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THE MUFULIRA COPPER DEPOSIT, NORTHERN RHODESIA.

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INTRODUCTION.

Mufulira Mine is in the N'Kana Concession, in the Rhodesian, or southern, part of the Central African Copper Belt (Fig. 1). The copper-bearing outcrops on the property were discovered many years ago, and when the writer first visited the place, in August, 1927, several trenches and shallow pits had been dug on them. This work had been done some years before, and the prospect abandoned.

In June 1928, the first drill-hole on the property, put down by the Rhodesian Selection Trust, was completed. This hole encountered ore at a depth of about 100 meters, and since then twenty-nine holes have been drilled in ore, the deepest of which struck the lode at 1000 meters. These holes cover a strike length of two kilometers, and indicate ore bodies of 116,000,000 tons, averaging 4.4 per cent. copper. Fig. 2 shows the position of the drill-holes and the surface traces of the ore bodies.

At the present time a railway has been constructed to the property, considerable development work has been done to a depth of about 115 meters below the surface, and a mill is under construction. It is expected that production will start early in 1932 with an initial output of 1500 tons per day.

Mufulira is destined to be a large and important producer of copper. However, except for the statement of the known size of the deposit given above, and the fact that no insuperable difficulties of mining have as yet been or are likely to be encountered, this paper is not concerned with the economic possibilities and prospects of the mine. It is a description of the geology of the deposit as known today, and the writer's views on the geological processes which have formed it.

GENERAL REGIONAL GEOLOGY.

A brief statement of the general geology of the copper belt will be necessary for an understanding of the geological setting of the Mufulira deposit. For more detailed descriptions of the regional geology and the copper deposits, several publications are available.[1]

The topography of the Copper Belt is, in general, slightly rolling, with only occasional ridges formed by the more resistant rocks. The average elevation of the ground is about 1200 meters, and the higher parts represent an old peneplain, re-elevated in comparatively recent times. A new cycle of erosion has just commenced, and many streams are beginning to entrench themselves in their old course.

Except for a considerable amount of swampy ground the region

[1] Studt, F. E.: The Geology of Katanga and Northern Rhodesia. Geol. Soc. of S. Africa, 1913. Robert, M.: Le Katanga Physique. M. Lamertine, rue Condenberg, Brussels, 1927. Van Doorninck, N. H.: De Lufilische Plooing. G. Naeff, The Hague, 1928. Bancroft, J. A., and Pelletier, R. A.: Notes on the General Geology of Northern Rhodesia. Mining Magazine, London, Dec., 1929, Jan., Feb, March, 1930. Gray, Anton, and Parker, R. J.: The Copper Deposits of Northern Rhodesia. E. & M. J., vol. 128, 1929. Gray, Anton: The Correlation of the Ore-Bearing Sediments of the Katanga and Rhodesian Copper Belt. Econ. Geol., Dec., 1930. Bateman, Alan M.: The Ores of the Northern Rhodesia Copper Belt. Econ. Geol., June–July, 1930. Schuiling, H. J.: The Structure of Kambove Mine. Int. Geol. Congress, 15th Session, 1929. Sharpstone, D. C.: Geology and Development of the Roan Antelope Mine, Northern Rhodesia. Third Empire Min. & Met. Congress, S. Africa, 1930. Davidson, D. M.: Geology and Ore Deposits of Chambishi, Northern Rhodesia. Econ. Geol., March–April, 1931. Schneiderhöhn, H.: Mineralische Bodenschätze im Südlichen Afrika. Berlin, 1931. Northern Rhodesia, pp. 84–103.

is covered by forest. The rainfall occurs almost entirely between the months of November and April, and amounts to from 100 to 150 centimeters per season. The mean annual temperature is about 20° C. Rock weathering exists to exceptional depths, and the soil covering varies from nothing to 25 meters, averaging probably 10 meters in thickness. Rock outcrops are exceedingly scarce.

The general geologic column for the copper belt is as follows:[2]

VI. *Lubilash System* (Karroo).
Permian to Jurassic.
Unconformity.
V. *Intrusive Rocks.*
Gabbro and diabase sills and dikes.
Younger gray granite.
IV. *Katanga System.*
2. Kundelungu series.
1. Mine series *Copper Deposits.*
Unconformity.
III. *Granite Intrusives.*
II. *Muva System.*
Unconformity.
I. *Lufubu System.*

The Lufubu and Muva systems are composed of ancient schists and gneisses. Together with the older granites they form the "basement complex" upon which were laid down the sediments of the Katanga system. The lower series of this system, the Mine series (Fig. 3), has an average thickness of about 1500 meters, and is divided into three groups. The Lower Roan group rests unconformably on the eroded surface of the "basement complex." It is composed of continental sediments, arkoses and sandstones largely, with some relatively thin beds of shale and dolomite. The thickness, particularly of the lower conglomerate beds, is very variable, and the character of the sediments changes considerably in short distances. In general, however, it may be divided into two parts. The lower is made up almost wholly of feldspathic sandstones and conglomerates; the upper consists of sandstones

[2] The names used are those which have been adopted by the writer. For a correlation with the nomenclature used by other writers, see Anton Gray, *op. cit.*

alternating with shales and thin beds of dolomite. This group of sediments contains the Mufulira copper deposits.

The Upper Roan group consists of about 550 meters of dolomite and dolomitic shale, and includes the copper-bearing

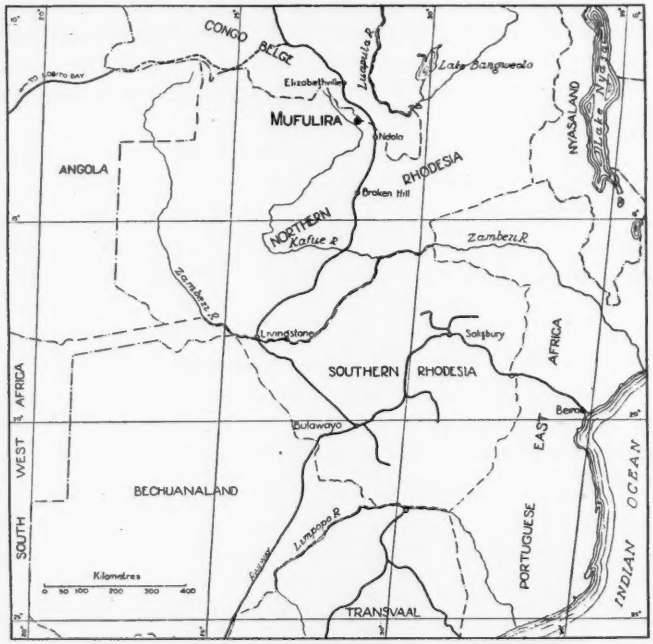

FIG. 1. Index map showing position of Mufulira.

dolomites of the Belgian Congo. The M'Washia or Upper group of the Mine series consists principally of shales with interbedded sandstones. Overlying the Mine series conformably are the Kundelungu beds, several thousand meters in thickness.

The rocks of the "basement complex" and the overlying Katanga system are highly folded and in places faulted. During or following this folding they were intruded by large masses of granite, the "younger gray granite." This intrusion was accompanied by mineralization, and the copper deposits of the region

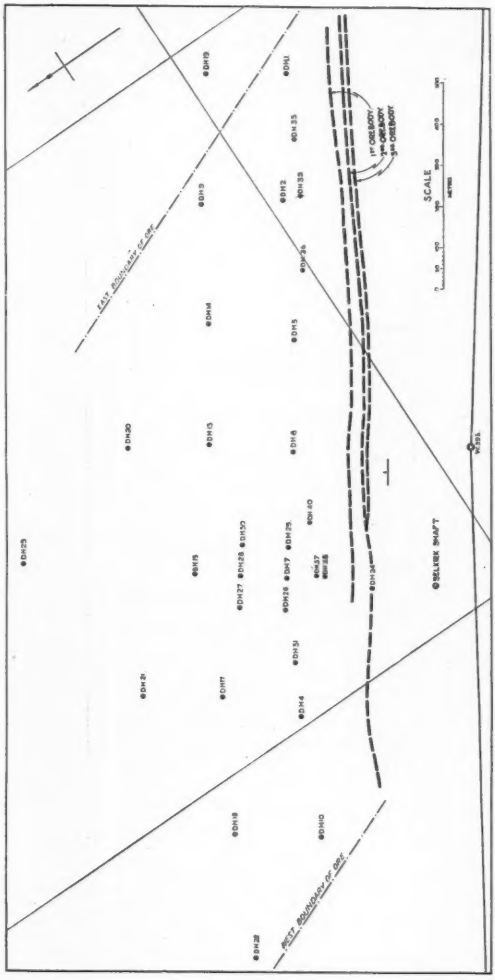

FIG. 2. Drill holes and traces of ore-bearing horizons, Mufulira Mine.

were formed at this time. Copper-bearing veins and stockworks were formed in the schists near the granite margins, and pegmatites with copper minerals formed in and around the granite. The

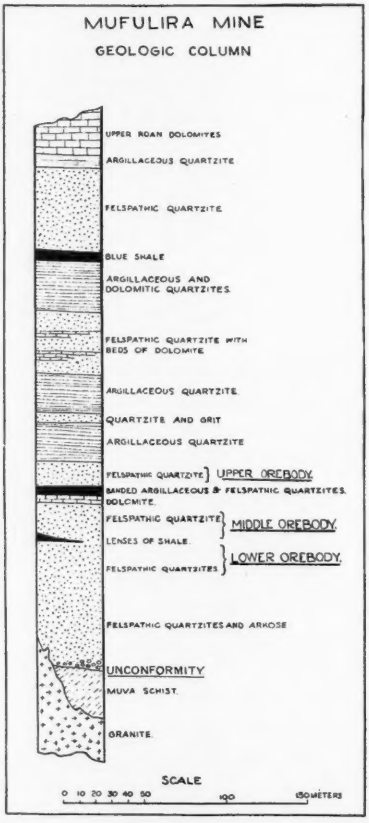

FIG. 3. Geologic column, Mufulira mine.

important mineral deposits, however, were formed in the sediments of the Mine series. In addition to forming small veins, the mineralizing solutions spread along certain favorable beds

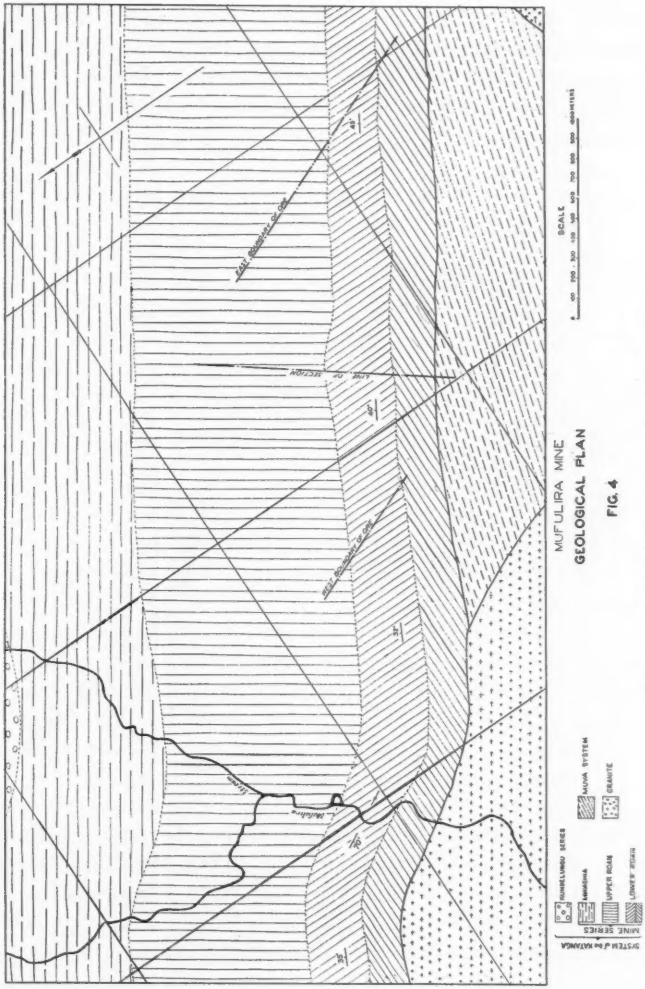

FIG. 4. Geological plan of Mufulira mine.

for unusual distances, impregnating them with copper sulphides, associated with iron and smaller amounts of cobalt. Most, if not all, of this mineralization took place after the folding, and the shape and concentration of the deposits were controlled by the folded or faulted structures of the beds. The basic intrusions, gabbro and diabase sills, are definitely later than the folding.

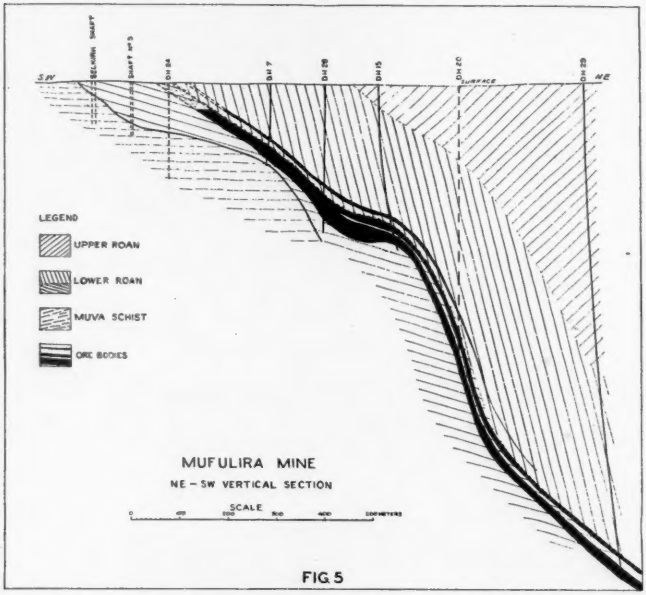

FIG. 5. Vertical section, NE–SW, Mufulira mine.

After the folding of the Katanga system, and intrusion of the granite, the region was again base-leveled and the Permian to Jurassic beds of the Lubilash, or Karroo, system were deposited. This was followed by uplift, not accompanied by any marked folding, however, and further erosion. This continued till recent times and resulted in the peneplain which forms the main feature of the present topography.

During the latter part of the period of peneplanation, rock weathering and decomposition extended to great depths. There is abundant evidence that either just before or since the latest uplift, very arid climatic conditions prevailed in the region.[3] The ground water table must have been very deep, for oxidation and leaching of the rocks are found at depths of 600 meters, far below the present water level. It is only recently that the climate has become moist, the rocks saturated to within a few meters of the surface, and the ground covered with vegetation. The very recent uplift which produced the present elevation of the region, except for its effect on climate and slight rejuvenation of the streams, has had as yet no important geological consequences.

This discussion of general geology may seem somewhat lengthy in a paper intended to describe a mine, but this particular mine cannot be understood apart from its setting. The outstanding problem at Mufulira is the origin of the sulphides which form the ore, whether they be epigenetic or syngenetic, hypogene, supergene, or both; and if both, their relative proportions. Well informed opinion is by no means in unanimous agreement on this subject. The reader is asked to keep in mind the formation of a very ancient and deep-seated deposit of copper sulphides; the long continued erosion of the overlying rocks, at first under the climatic and topographic conditions of a mountainous region, later reaching a stage probably approaching base level; the deposition of an overlying fairly thick system of sediments; uplift and further long continued erosion, resulting finally in a peneplain on the surface of which the upper part of the copper deposit was exposed; an arid climate and deep water level existing for a considerable period after the formation of the peneplain; and finally a change to a moist climate, saturating the ground to within a few meters of the surface. All these events and conditions have played their part in forming the Mufulira Copper Deposit.

ROCK FORMATIONS AND STRUCTURE.

The structure at Mufulira is extremely simple. It is shown in plan in Fig. 4 and in section in Fig. 5. The sediments of the

[3] Bateman, Alan M.: *op. cit.*, pp. 381–384.

Katanga system rest unconformably on Muva schists. They strike about northwest and dip to the northeast. Both strike and dip fluctuate, but no faults have been observed within the mine area.

The granite shown in the western corner of the area is younger than the Katanga system. It has not penetrated far into the sediments, but the latter are highly silicified near the contact and contain numerous dikes of granitic material, as well as an unusual number of quartz veins. Blocks of silicified quartzite have been found entirely surrounded by granite, and granitic material follows the bedding planes in a sort of *lit par lit* structure. This granite contains many small quartz-pyrite-chalcopyrite veins.

The Muva schist, or micaceous quartzite, is a dense, tough rock which breaks with a blocky parting due to numerous and closely spaced joints. It is a thoroughly re-crystallized rock in which all traces of bedding have usually been obliterated. The mica is muscovite, and very subordinate in amount to quartz. Many granite, aplite and pegmatite dikes are found in the schist. There are also small quartz veins carrying copper sulphides. Most of these dikes and veins follow joints. They show no sign of deformation.

Of the Katanga system, only the Lower Roan group must be considered in detail. It lies unconformably on the Muva schist, and is overlain conformably by the calcareous shales and dolomites of the Upper Roan.

The Lower Roan may be divided into two formations. The lower formation is variable in thickness and typical of a rock formed under shallow water conditions. It is composed largely of feldspathic quartzites, some evenly bedded, some coarsely cross-bedded. A meter or so of basal conglomerate is present in some places, and conglomerate lenses occur at various horizons. Thin bands of mudstone occur, only one of which, about twenty meters from the top, is persistent for any distance.

The upper formation consists of alternating beds of feldspathic and argillaceous quartzites, with a few thin dolomites. These beds are fairly persistent in thickness over the mine area. As shown in the geologic column (Fig. 3), the lowest bed, a dolomite,

is three to five meters thick. This is followed by about five meters of banded argillaceous quartzite, and this in turn by about fifteen meters of feldspathic quartzite. Then comes a bed of argillaceous quartzite, about twenty meters thick, followed by alternating feldspathic and argillaceous quartzite to the top of the formation.

All these sediments have been considerably metamorphosed. The feldspathic quartzites consist almost entirely of re-crystallized quartz and feldspar in a cement of sericite. Quartz makes up from 60 to 75 per cent. of the rock, and the feldspar is largely microcline, although there is some plagioclase.

The argillaceous rocks have been re-crystallized to a dense fine-grained mass of quartz and sericite. Some phlogopite and epidote are present. The dolomite is completely crystalline and contains some quartz intergrown with the carbonate, and in places a considerable amount of phlogopite. Most of this re-crystallization is probably due to the nearby intrusive granite. There has been little dynamic metamorphism. A slight schistosity has developed in the more argillaceous beds.

Jointing in the lower formation is well developed and the joints are rather closely spaced. Four sets are distinct. Of these the best developed strikes about N 40° E and dips 83° to 87° NW. These joints nearly always contain quartz veins, many of which carry specular hematite, others copper sulphides. They appear to die out or become very tight in the denser argillaceous rocks.

Another set parallels the bedding. These are well developed and also contain quartz and sulphide stringers. The remaining two sets, with strikes of N 25° W and N 70° E respectively, and steep dips, are poorly developed and usually tight. They are not known to contain sulphides.

In the upper formation, particularly in the denser rocks, jointing is much less well developed. The set following the bedding is commonly quite distinct, but the vertical joints disappear to a large extent when the argillaceous and dolomitic rocks are reached.

WEATHERING.

Weathering of the rocks has been extreme and has reached unusual depths, far below the present ground water level. This varies from 0 to 50 meters depending on the underlying rock and the distance from the stream.

The granite and Muva quartzite form numerous fairly large outcrops. On these the rock may be practically fresh on the surface, and several of them have been quarried for building stone. On the other hand, a few meters from the outcrop the rock (particularly granite) may be thoroughly decomposed to a depth exceeding 10 meters. Near the sedimentary contact this depth of decomposition rapidly increases.

The Lower Roan quartzites, particularly where mineralized and silicified, form numerous small outcrops, in some of which the rock is quite fresh. The argillaceous quartzites form a few outcrops but these are usually well decomposed. The silicified dolomites rarely form outcrops of brown cherty rock. The other formations are not represented at the surface, and most of the area is covered by a thick overburden.

Rock decomposition has been far in excess of erosion for a great length of time. The result is the thick mixture of rich soil and laterite so typical of tropical and sub-tropical countries. The red soil over the sediments is from 3 to 5 meters deep and is underlain by from 10 centimeters to 2 meters of a lateritic formation. The structure of this rock is concretionary, and it is composed entirely of limonite and hematite with residual quartz from the original rock. Downward, this laterite merges gradually into the decomposed bed rock.

The depth to which weathering has taken place in the sediments is extremely variable. A drill may cut many alternating beds of firm fresh rock and completely oxidized and weathered rock. The extreme case of this at Mufulira was in drill-hole No. 29, which after passing through over a hundred meters of fresh rock, encountered a thoroughly decomposed and obviously oxidized bed at over 600 meters. In this same hole the condition of the dolomites is extremely suggestive. Fresh undecomposed beds

alternate in several places with leached, silicified and porous rocks resembling the silicified dolomite outcrops of the Katanga.

The oxidizing and decomposing surface waters have obviously followed the planes of bedding, and this is clearly shown in the mine openings, as well as the drill-holes. Furthermore, weathering at depth is practically confined to certain beds. The coarse arkosic quartzites are most altered. The cement is leached, the feldspars decomposed and in places wholly kaolinized. Limonite staining may be found at depths of several hundred meters. The result is a soft porous rock that disintegrates to a loose sand almost immediately on exposure to the air.

Some dolomites, as found in drill-hole No. 29, are probably affected nearly as deeply as the feldspathic quartzites. Other dolomites, as the bed lying just above the second ore-body, are not affected so deeply. This rock may be altered to a porous mass of brown chert at a depth of 150 meters, but in other places it has been found quite unaltered at 110 meters.

The dense argillaceous rocks and the ore-bearing quartzites, in part, are least of all affected. They are usually quite fresh and unaltered at a depth of 50 meters, though parts of the mineralized quartzites are weathered to much greater depths.

Such weathering cannot be accounted for by present topographic and water conditions. The idea of an artesian circulation reaching such depths with the present water level in existence has little in fact to support it. For a long time the country has been flat and there have never been any points of discharge more than about 50 meters below the present surface of the ore body.

Many facts point to an arid climate in the region in recent geologic times, and this is now generally accepted. The ground water level must have been very deep and there must even then have been some circulation of oxygenated waters below the average water table. What descending surface waters there were chose the most porous or soluble beds in which to circulate. Once started, they would have the effect of making them still more porous, by solution and leaching, down to the then existing water table. Their oxidizing effects would probably, and evidently did,

go deeper still. Other beds, more impervious, were affected hardly at all, even near the surface.

This deep zone of weathering has now been submerged by the rising water level resulting from the recent change from an arid to a moist climate.

THE ORE BODIES.

There are three ore bodies, or "lodes," at Mufulira. These consist of disseminated copper and iron sulphides occurring at three distinct horizons in the Lower Roan group of the Mine series. Fig. 2 shows the surface traces or "sub-outcrops" of the lodes, and Fig. 5 shows their location in section. Of the three, the lower one has the greatest extent along the strike, and drill-hole 29 indicates that it also has the greatest extent in depth, as in that hole it is 12 meters thick and of average mine grade, at a vertical depth of 1000 meters. The middle lode is quite distinct from the lower in the eastern part of the deposit, but merges into it about opposite drill-hole No. 7. This lode is relatively thin and low grade in drill-hole No. 29. The upper lode is not known to connect with the other two in any part of the deposit. It does not extend so far to the west as do the others and is represented in drill-hole No. 29 by only a very slight mineralization of the horizon.

The lodes are tabular bodies up to 20 meters in thickness, and their attitude is that of the enclosing beds. Drilling has proved, however, that all three pitch to the north, as indicated by the boundary lines shown in Figs. 2 and 4. Their lower limits in the direction of pitch are not known.

The principal sulphides of the deposit are chalcocite, bornite and chalcopyrite. Pyrite, linnaeite, covellite and sphalerite have been found, but are rare. Of the oxidized ore minerals, malachite is by far the most abundant. Azurite, chrysocolla, cuprite and a black earthy mixture of copper, manganese and iron oxides are found in smaller amounts. Native copper occurs in patches, but is not important.

Some quartz and carbonates, and perhaps a very little tourmaline, were introduced with, or just before, the sulphides. The

amount of these minerals, however, is very small, and the gangue of the lodes is the altered feldspathic quartzite. The percentage of sericite is much higher, and of feldspar much lower, in the lodes than in the unmineralized quartzite. As the sulphides are invariably later than the sericite, it would seem that the mineralization was preceded by considerable hydrothermal alteration of the rock silicates, and this alteration, as might be expected, was most intense in the beds through which the greater part of the metallizing solutions passed.

Both sulphide and oxidized minerals are practically confined to the three "ore horizons" mentioned above, and to the small veins in the footwall rocks. This stratigraphic position of the ores is of great importance in an understanding of the origin of the deposit. Referring to the geologic column (Fig. 3), it will be noted that the horizon of the lower ore body is the quartzite lying just below the lowest shale lenses shown. The middle ore body lies just below the lowest dolomite. In the eastern part of the deposit, the shale above the lower ore body is about 30 centimeters thick, but to the west it becomes thinner and the point at which it nearly disappears corresponds to the point at which the lower and middle ore bodies merge to form a single, and much wider lode.

The sulphides of the middle lode may penetrate into the dolomite for a meter or so, but never more. This dolomite and the dense quartzite above it are persistent beds over this area, and the middle lode invariably lies just below them, completely separated from the upper lode.

In the same way, the dense argillaceous quartzite found just above the horizon of the upper lode invariably marks the hanging wall of this ore body. A few scattered sulphide grains may be found in this rock 10 or 15 centimeters from the lower contact, but usually it is absolutely barren.

Fig. 6 shows, diagrammatically, and in a generalized manner, the distribution of minerals in a section of the lodes. Note that, for convenience, this figure is not drawn to scale either horizontally or vertically. It does not indicate the small amounts of

sulphides that occur in the oxidized zone. Neither does it indicate predominance of bornite or chalcopyrite in the inner zone. No distinct bornite or chalcopyrite zones have been detected. Comparison with Fig. 5 will show the zones in their true dimensions.

With the exception of scattered remnants of sulphides, oxidation is practically complete above the present water level, and the

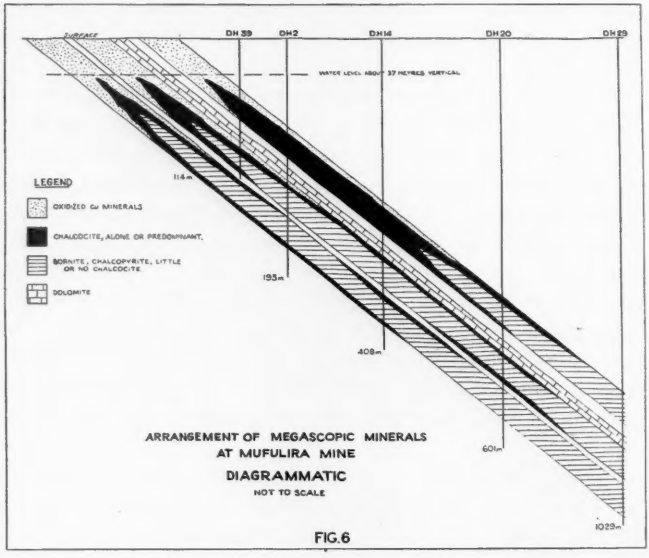

FIG. 6. Arrangement of megascopic minerals, Mufulira mine

greater part of the copper has been leached from the rock. The most abundant oxidized copper mineral is malachite, which occurs disseminated through the decomposed quartzite in small particles, and to a lesser extent as small veins. Chrysocolla occurs near the surface, filling cracks and coating joint surfaces. Azurite is rare and commonly shows replacement by malachite, probably the result of the change from a dry to a moist climate. Black and red stains of copper and iron oxide are common and boxwork structures of limonite after sulphides are found in the less decomposed rock.

Cuprite is rare and is mostly found closely associated with chalcocite, which it replaces. Some native copper occurs, also associated with chalcocite. The largest concentration of native copper yet found is in drill-hole No. 14 (Fig. 8), in the oxidized hanging wall of the upper ore body.

The oxidized zone extends far below the present water level. It is deepest on the hanging wall of the upper ore-body and the footwall of the lower. There are exceptions to the general rule that oxidation follows down the hanging and foot walls, but they are rare below 200 meters. Down to 600 meters there is almost invariably some oxidation just above and just below the ore.

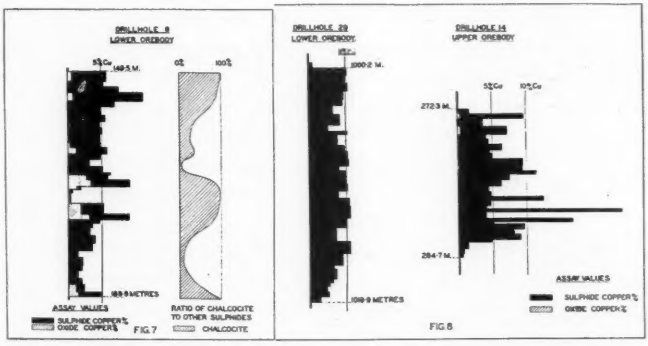

FIG. 7. Ratio of chalcocite to total sulphides contrasted with assay plan of sulphide and oxide values in drill hole 8.

FIG. 8. Contrasted assay plans of drill hole 29, in hypogene ore, and drill hole 14, showing effect of supergene enrichment.

In the chalcocite zones, which in position and relation to the lodes resemble closely the oxidized zones, both oxidized minerals and bornite and chalcopyrite may be present. Much of the chalcocite, under the microscope, is found to contain cores of bornite and chalcopyrite, particularly in the lower parts of the chalcocite zone. The assay plans show a decided tendency for oxide copper and chalcocite to occur together. Fig. 7 shows the assay plan of the lower ore body in drill-hole No. 8. The assays are plotted

graphically and the approximate ratio of chalcocite to total copper sulphides is shown by a curve. The tendency of chalcocite and oxide copper to occur together is obvious.

No systematic arrangement of bornite and chalcopyrite has yet been recognized. In the deposit as a whole bornite predominates over chalcopyrite at least 3 to 2. In drill-hole No. 29 (Fig. 8) the central portions of the lower and middle ore bodies are high in bornite, and the outside portions are high in chalcopyrite. The hanging wall rocks contain a little pyrite. The upper ore body in drill-hole No. 13 is unusual in that the hanging wall is not oxidized. Considerable pyrite occurs just above the ore. The upper part of the lode consists of chalcopyrite. Bornite appears and increases until near the center of the lode it is the only mineral. The footwall part of the ore body contains bornite and chalcocite.

In drill hole No. 13, lower ore body, the position is reversed, the center of the lode being high in chalcopyrite. In other holes bornite and chalcopyrite predominate alternately. Either may occur alone, bornite more often than chalcopyrite, but commonly they occur together. It is true that some of the shallow and intermediate holes show ore with a higher percentage of bornite than the deep hole, No. 29, but this is not true in all cases and it cannot be said, on the basis of present information, that bornite is giving way to chalcopyrite at depth.

A very little chalcocite occurs with the bornite in all the drill holes, even the deepest.

There are two further features that should be noted in connection with the distribution of minerals. One is that the values in the eastern part of the deposit are higher than those in the western part, and the chalcocite zone is deeper in the eastern area. This will be mentioned again in the discussion on the genesis of the deposit.

The second feature is that the chalcopyrite overlaps bornite along the strike. That is, it occurs in the ore horizons beyond the area of payable ore and beyond the area containing bornite. The chalcopyrite in turn is overlapped by pyrite, which appears to be the most persistent of the sulphides. Pyrite predominates

in the veins near the granite and occurs in the sediments farther from the granite than any of the copper sulphides.

THE ORES.

The ore at Mufulira is found almost wholly in the feldspathic quartzites. Very rarely it penetrates a few centimeters into the overlying dolomite. It is epigenetic, the ore minerals replacing rock silicates including metamorphic minerals such as phlogopite and recrystallized feldspar, as well as sericite, dolomite, and to a lesser extent quartz. The sulphides occur mostly as discrete, irregular-shaped particles averaging 0.7 mm. in diameter. Many are much smaller, a few, particularly of chalcocite, are larger. The particles are scattered through the rock in varying concentration. The sulphides also occur in small veinlets, and rarely in masses up to 5 cm. in diameter. In the veinlets and larger masses the sulphides are often associated with, and later than, quartz and carbonates. With the exception of oxidation products and a little supergene quartz, the sulphides are the latest minerals of the ore.

The gangue consists of the minerals of the feldspathic quartzite. This rock, however, has been altered in and near the ore. It contains about the same amount of quartz, but much less feldspar than the unmineralized quartzite, and a great deal more sericite. It evidently underwent a considerable amount of hydrothermal alteration, and the introduction of some quartz and corbonates, before the sulphides were introduced.

Some of the ore-bearing quartzite has been called graywacke, on account of its dark blue-gray color. The composition of this rock is much the same as that of the ordinary feldspathic quartzite. In some of it the color seems to be due to very minute specks of graphite. This rock occurs only in the ore horizon.

The relation of the sulphides to the host rock is sufficiently clear. The relations existing between the various sulphide minerals themselves, however, are more complex.

Pyrite is very rare in the ore, but occurs in grains with well developed crystal faces that cut across all rock silicate. It clearly

replaces the rock minerals, but replaces no other sulphides. It is replaced by chalcopyrite and chalcocite.

Chalcopyrite occurs in grains of the pure mineral and associated with the other sulphides. It replaces rock minerals and pyrite. The grains or veinlets are irregular and show no crystal form. It occurs in composite grains with bornite, the mineral boundaries being sharp, evenly curved or straight, and the arrangement of the minerals such that neither can be said to replace the other. The intergrowth might be contemporaneous. In many of the composite grains however, the arrangement of the minerals definitely suggests replacement of chalcopyrite by bornite. The bornite surrounds and penetrates the chalcopyrite in sharp identations, which are rarely deep enough to resemble veinlets. Chalcopyrite is definitely replaced by chalcocite at a depth of 1000 meters as well as near the surface.

Bornite occurs alone, replacing rock silicates, and in composite grains with chalcopyrite as described above. It has not been observed to replace any sulphide except chalcopyrite. It is replaced by chalcocite at all known depths, one of its most frequent occurrences at shallow depths being remnants in chalcocite grains.

Chalcocite replaces pyrite, chalcopyrite, bornite and linnaeite. It is replaced by no other sulphide, with the possible exception of covellite. It is in places fractured and traversed by small quartz veinlets, near the surface. Chalcocite occurs as grains and veinlets of the pure mineral. It occurs as replacement rims around grains of other sulphides, or as veinlets cutting them. All stages of replacement by chalcocite are found, from the narrow rim of the mineral to the grain of chalcocite containing small irregular remnants of the replaced sulphide, or to the grain of pure chalcocite. Complete or nearly complete replacement of bornite and chalcopyrite by chalcocite is typical of the chalcocite zones shown in Fig. 6. At great depth, as in drill-hole No. 29, rims of chalcocite are not found. The chalcocite appears to attack the other sulphides irregularly, in some cases on the outer edge of the grain, in others around inclusions of gangue minerals. The chalcocite here too contains remnants of the replaced sulphide.

In the replacement of bornite by chalcocite a triangular pattern is commonly formed. A pure chalcocite rim changes gradually to a zone in which chalcocite is arranged in bornite in the form of a triangular lattice. Toward the center of the grain chalcocite decreases in amount until the lattice pattern gives way to a few irregular veinlets of chalcocite. In the center there may be a core of pure bornite.

Linnaeite is rare in Mufulira. One octahedral crystal about two centimeters across was found associated with vein-quartz at a depth of about 50 meters. It was coated with chalcocite.

Sphalerite has been observed in a few small isolated particles.

Covellite was found in small amount in the shallow drill-holes, associated with chalcocite.

Malachite and azurite are obviously supergene, and result from the oxidation of all the copper sulphides. Azurite is rare, and is replaced by malachite.

Chrysocolla is found in joint planes and other fissures near the surface.

Native copper and cuprite occur only associated with chalcocite. They have been found only in that part of the deposit shown as "chalcocite zone" or "oxidized zone" in Fig. 6. Cuprite replaces chalcocite.

The writer was not able to distinguish under the microscope, two distinct ages either of chalcocite or bornite. Part of the bornite may be contemporaneous with, and part later than chalcopyrite, but there is nothing to indicate a break between the deposition of the two. Microscopically then, the paragenesis of the ore minerals is: Pyrite, chalcopyrite, bornite, chalcocite.

GENESIS OF THE DEPOSIT.

From the foregoing description it is clear that the Mufulira deposit is epigenetic. The copper sulphides were introduced into the sediments after the folding and metamorphism of the latter, and formed by metasomatic replacement of the rock silicates. The source of the mineralizing solutions was probably the magma of the nearby granite. The mineralization took place after the margins of the granite, at least, had solidified.

The mineralizing solutions reached the sediments most probably through tension cracks in the cooled granite margin, joint cracks in the Muva schist and joints in the basal Mine series quartzites, in all of which they formed sulphide-bearing veins. Only on reaching the impervious shaly and dolomitic beds of the Mine series did they spread out through the sediments to form the large ore bodies which are being developed (Fig. 9).

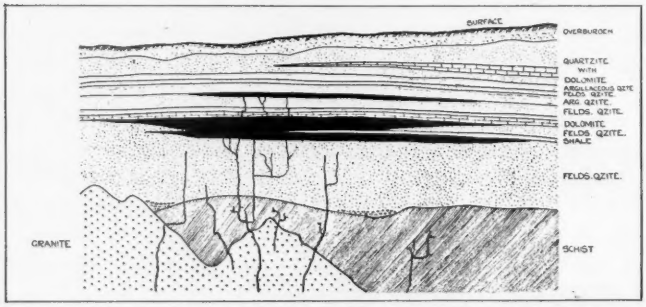

FIG. 9. Diagrammatic longitudinal section to illustrate formation of ore bodies.

The stratigraphic position of the ore bodies is clearly due to the damming action of the dense and unfractured overlying beds. The shale overlying the lower ore body is narrow and discontinuous, and much of the copper penetrated to the overlying quartzite, forming the middle ore body. Only a small amount of the solutions found a path through the dolomite and shaly quartzite over the middle ore body, and the upper ore body is the smallest of the three. The thick shaly quartzite above the upper ore body formed the final barrier, past which none of the mineralizing solutions penetrated.

The solutions must have been highly fluid, for they penetrated along the sediments, through capillary or sub-capillary openings for distances of over a kilometer. That their temperature was fairly high is indicated by the specularite and tourmaline in the sulphide-bearing veins. The regional geology and structure indicates that the deposit was formed between two and four

thousand meters below the surface. It is to be classified under Lindgren's " mesothermal " deposits.

Pyrite and chalcopyrite were deposited as hypogene minerals. The origin of bornite is not so obvious. It replaces chalcopyrite, but there is no obvious zoning of chalcopyrite and bornite, and bornite is abundant in the deepest drill-hole, No. 29, at a vertical depth of 1000 meters, and a depth down the dip of the lodes of almost 1500 meters. The abundance of bornite seems to have no relation to the present surface, or to horizons of leaching and oxidation. Its textural relations with chalcopyrite indicate that some of it, but not the greater part, may have been deposited practically contemporaneously with chalcopyrite. The writer's conclusion is that nearly all, if not all, of the bornite is hypogene. There remains the possibility that some of the veinlets of bornite, associated with chalcocite at shallow depth, in chalcopyrite, may be supergene. But this represents a minute percentage of the total bornite.

The distribution of chalcocite, on the other hand, shows a very obvious relation to the surface and to the horizons of deep leaching and oxidation. In the upper ore body, above the dolomite, the chalcocite zone is deep. In the ore below the dolomite it is only deep on the hanging and foot walls (Fig. 6). The shapes of the chalcocite zones follow faithfully the shapes of the leached and oxidized zones. Fig. 7 shows the relation of chalcocite to oxidized copper in a single drill hole.

In drill hole 29 the ore is almost wholly chalcopyrite and bornite. This is primary ore beyond a doubt. Fig. 8 shows a graphic representation of the copper values over the width of the lode. The grade is fairly consistent over the entire width. The upper ore body in drill-hole 14, shown for comparison, is in the chalcocite zone. The ore is enriched in spots, and contains bunches of high grade not found in the deep primary ore. This is typical of the chalcocite holes, particularly the shallow ones. There is a definite enrichment in the chalcocite zone. This enrichment is also shown in Fig. 7.

Chalcocite exists deep below the present water table. But in the recent past the water table was much lower. Oxidation and

leaching of the beds at 600 meters proves the circulation of oxygenated surface waters to that depth. The circulation which could produce oxidation at that depth could probably also produce the formation of supergene chalcocite.

Microscopically, the most typical textural relationship of chalcocite to bornite or chalcopyrite is that of "rim replacement," or grains of chalcocite with remnants of the other sulphides. Bateman [4] shows some excellent photomicrographs of Mufulira ore. His Fig. 14 (Fig. 10) shows a lattice intergrowth of chal-

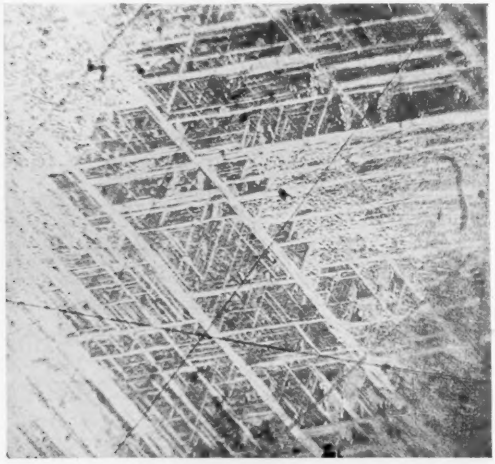

FIG. 10. Lattice intergrowth of chalcocite (white) and bornite (dark). Note triangular isometric pattern. Mufulira mine, Bore Hole No. 5. × 600. (Bateman's Fig. 14.)

cocite and bornite showing triangular isometric pattern. He suggests that it is due to replacement, the pattern of the chalcocite being due to control by the isometric cleavage of bornite. I agree absolutely, having observed the same texture where a rim of chalcocite was forming around a core of bornite, as described above, and under conditions which indicate supergene replacement.

[4] Bateman, Alan M.: *op. cit.*

In his Figs. 11 (Fig. 11) and 12 (Fig. 12), Bateman shows Mufulira chalcocite with "lamellar microstructure," a triangular structure of blue and white chalcocite brought out by etching. It is interpreted as proof that the chalcocite was originally the isometric high-temperature variety. With this interpretation I do not agree.

This specimen comes from Mufulira drill-hole No. 1. It is on the upper edge of the ore body and the only ore mineral is chalcocite. The holes nearby and just down the dip contain bornite and chalcopyrite in addition to chalcocite, and they show abundant examples of chalcocite replacing the other sulphides with the "rim," "veining" and "mesh" structures typical of supergene replacement. I would suggest that this lamellar micro-structure might be formed by the complete replacement of bornite by chalcocite, the replacement being controlled by the bornite cleavage as in the triangular lattice structure.

The distribution of chalcocite, its relation to weathering and leaching, and the microscopic textures observed, lead me to conclude that most of it at Mufulira is supergene. In this category I include practically all the chalcocite in the chalcocite zones shown in Fig. 6.

The chalcocite in drill-hole 29 is not confined to any part of the lode. It is found in small amounts wherever there is bornite, which it replaces. It is not accompanied by any oxidation, and the rock appears absolutely fresh. There is no evidence of supergene action. This chalcocite is probably hypogene, and may indicate the proportion of chalcocite originally deposited throughout the ore bodies. The low pyrite content of the ores indicates the low iron and sulphur content of the mineralizing solutions, and there seems to be no reason why hypogene chalcocite should not have been formed.

If the chalcocite of the upper zone be supergene, it can be calculated approximately from what height above the present surface copper must have been leached to form the enrichment shown by sampling, assuming a fairly even grade of primary mineralization. For the upper ore body such a calculation gives a height of about forty meters above the present surface. This corresponds closely

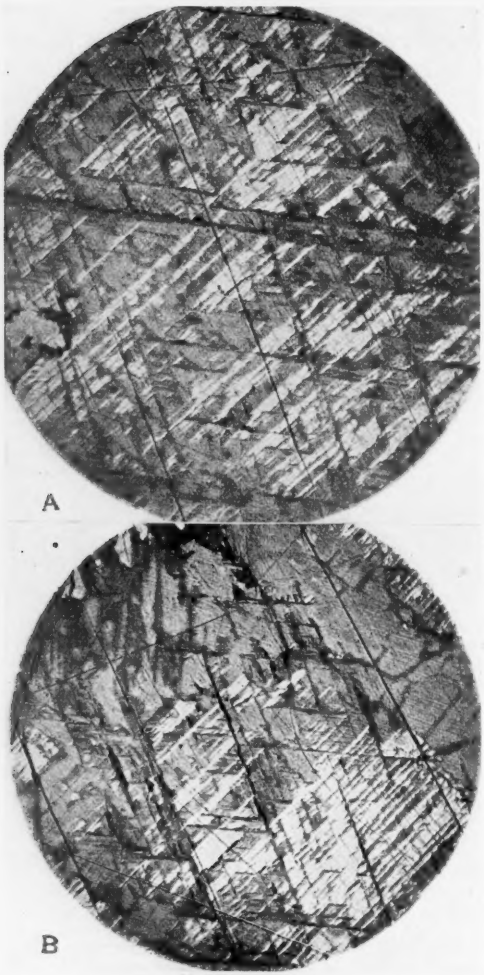

FIG. 11. Lamellar microstructure of blue and white chalcocite, showing isometric pattern, stated by Schneiderhöhn to be proof of high-temperature chalcocite. Slight rotation under crossed nicols shows up the color bands in other directions. Different fields of the same specimen under crossed nicols. Mufulira, Drill Hole No. 1. *A*, × 230; *B*, × 190. (Bateman's Fig. 11.)

to the elevation of the peneplain which existed before the present cycle of erosion commenced. For the middle and lower ore bodies the calculated height is less. Any part of the deposit extending above the level of the peneplain, then, must have been carried away during the process of erosion. Supergene enrichment commenced after the country had been practically base-

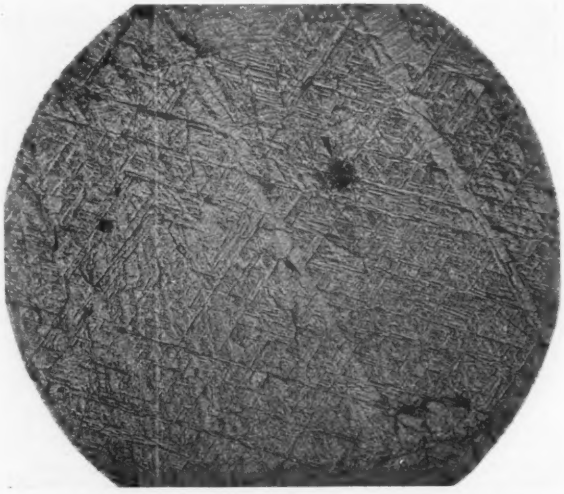

FIG. 12. Lamellar microstructure of etched chalcocite. Note triangular, and some rectangular patterns. Mufulira, Bore Hole No. 1. × 110. (Bateman's Fig. 12.)

leveled. Most of the deep enrichment probably took place during the period of arid climate.

It has been stated that the chalcocite zone is deeper and richer at the east end of the deposit than at the west end. This would be expected if the chalcocite be supergene and it is remembered that the lodes dip northeast and pitch to the north. Over the eastern end there was abundant copper to be leached, carried down and

reprecipitated as chalcocite. Over the present western end were practically barren rocks.

CONCLUSIONS.

1. Mufulira is an epigenetic, mesothermal deposit formed by solutions of igneous origin.

2. Deposition of the sulphides took place after folding of the sediments, and the form of the lodes was controlled by the structure of the beds.

3. The mineralized horizons were determined by the position of overlying impervious beds.

4. The sulphides were formed largely by metasomatic replacement of rock minerals.

5. The paragenesis of the sulphides is probably as follows: Hypogene—pyrite, chalcopyrite, bornite, chalcocite; Supergene—bornite (small amount), chalcocite.

6. Supergene enrichment took place after the formation of the Central African peneplain.

7. The age of the deposit is unknown, but is not later than late Paleozoic.

ACKNOWLEDGMENTS.

The writer is indebted to many people for help and advice during the work which resulted in the foregoing article. Particularly he wishes to express his appreciation of the kindness of the staff of the Geological Department of the Royal School of Mines, London, who placed at his disposal the facilities of their laboratories. Dr. W. R. Jones gave most valuable assistance. Drs. M. S. Fisher and G. C. A. Jackson assisted with the high power microscopic work and in taking photomicrographs.

Mr. W. B. Millar did much of the detailed mapping at Mufulira and collected many of the specimens which were examined.

Dr. Alan M. Bateman has given much guidance and help in the field work in Rhodesia. Although the writer does not agree with him as to the proportions in the ore of supergene and hypo-

gene chalcocite, he wishes to express his real appreciation of the help received during the work.

Finally, thanks are due to the directors and staff of the Rhodesia Selection Trust Ltd., and Mufulira Copper Mines Ltd., without whose foresight, courage and understanding the development of Mufulira could never have been accomplished.

ROYAL SCHOOL OF MINES,
LONDON.

GEOLOGY OF THE ZINC–LEAD DEPOSIT AT PECOS, NEW MEXICO—PART I.

PHILIP KRIEGER.

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INTRODUCTION.

THE Pecos ore deposit represents a complex mixture of zinc, lead and copper sulphides containing a minor amount of gold and silver. It forms lenticular masses within a broad shear zone. The country rock consists of ancient metamorphic schists, diabase, granite and related types of igneous rocks. A complex mixture of ore minerals of this type of occurrence is seldom found in quantity. The mine at Pecos, however, with a capacity

of 750 tons per day, is the second largest producing mine in New Mexico, in terms of calculated gross value of recoverable metals.

The shear zone in which the ore occurs is worthy of comment. It can be definitely traced along its strike for a distance of several miles in the vicinity of the mine, and may extend for a much greater distance both northeast and southwest. The shearing follows a zone of weakness in the older diabase of the district. It varies in width from a few feet to about 600 feet. It has been traced in the mine to a vertical depth of 1,500 feet, and probably extends much deeper. A major shear zone is bounded by parallel zones of lesser magnitude, with some cross shearing. The ore, which occurs as lenses within these zones, is prospected by following the strike of the rock structure and crosscutting wherever underground conditions appear favorable. From certain features observed in the underground workings it is believed that the shear zone has been developed along still older fractures in the diabase.

The general geologic setting is as follows: Pennsylvanian sediments overlie the pre-Cambrian rocks of the mine, and are separated from them by a great unconformity. A striking feature is the broad, uniformly even pre-Cambrian surface, which has a gentle dip of almost exactly 7 degrees to the southwest. Such an even surface, which has retained its uniformity of plane since pre-Cambrian time, suggests the absence of pronounced deformation. Notwithstanding the intense shearing developed before the pre-Pennsylvanian erosion, deformation since that time has been comparatively insignificant. Furthermore, the introduction of the ore, which is absent in the overlying sediments, appears to have occurred in pre-Cambrian time.

One of the interesting features of the ore deposit is the distribution of rounded, isolated blocks of more or less barren diabase, some of which have been silicified. They occur throughout the shear zone and the ores are found around these blocks as well as in portions of the shear zone between them, although it seldom occurs within the blocks themselves. They are believed to have originated in the fracturing of the diabase before shearing took place and were isolated by the injection of granitic

material around them. Later intense shearing and crushing gave them the rounded appearance they now have, and served to isolate them still further from the surrounding rock. The blocks vary in size from that of a hand specimen to more than 100 feet in longest dimension. The outer edges of these blocks are sometimes replaced by ore minerals, and their borders are altered to some extent in nearly every instance.

The petrologic relations of the country rocks are worthy of special mention. The rock history, as interpreted by microscopic study, points to igneous attack of variable intensity, with the infusion of end-stage magmatic juices into a diabase that had initially a considerable range in texture, and to a lesser degree in composition as well. This was followed by dynamic disturbance resulting in movement of sufficient intensity to form a broad shear zone, with subsequent replacement and mineralization of the schistose rocks affected by ore-bearing solutions. Deformation within the shear zone took place both before and during deposition of the ore.

Location and Accessibility.—The Pecos Mine of the American Metal Company, Limited, is located in northwestern San Miguel County, New Mexico. It is reached by a highway which skirts the southern end of the Sangre de Cristo Mountains and follows the Pecos River Canyon for 12 miles north of Pecos, New Mexico. The property is approximately 17 miles due east of Santa Fe and 27 miles west of Las Vegas, New Mexico. Glorieta, on the Santa Fe Railroad, is the nearest station. The ore is carried from the mine to the mill, near Pecos, by a twelve-mile aerial tramway. The mill is on a branch line connected with the Santa Fe Railroad.

History and Development.—What is now known as the Pecos Mine of the American Metal Company, Limited, was first discovered in 1881. In March, 1882, the Pecos River Mining Company was organized. It was not until 1905, however, when the property was known as the Hamilton, or the Cowles Mine, that any extensive development work was attempted. At that time development consisted mainly of a tunnel, driven into the ore body about on a level with Willow Creek, and a shaft, sunk

to a depth of approximately 200 feet. Between the years 1905 and 1910 this work was extended to a depth of 400 feet and levels were cut for the extraction of ore. At that time the property was worked primarily as a copper mine. The ore near

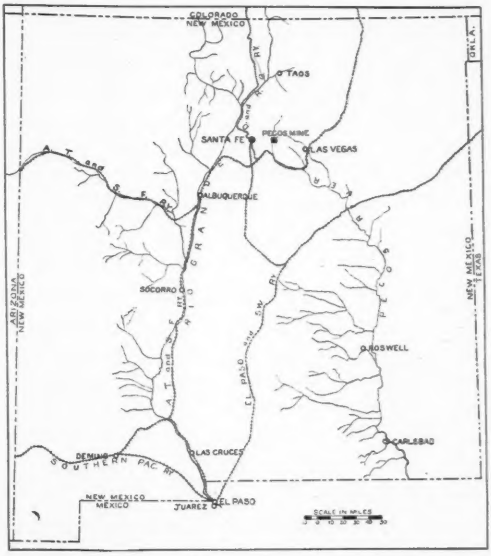

FIG. 1. Sketch map showing location of Pecos Mine.

the surface consisted mainly of irregular masses of pyrite, chalcopyrite and a small amount of sphalerite, with practically no galena. A small amount of ore was shipped, but there are no records available concerning the exact tonnage.

In 1916 the property was taken over by the Goodrich-Lockhart Company, which extended the scope of operations. An intensive program of development was inaugurated and sufficient ore was found to insure production for several years. As development was extended to greater depth, however, the ore became primarily a complex pyritic zinc-lead ore with only a small quantity of copper. Careful metallurgical research, carried on both in this

country and in Europe, resulted in finding a successful method for treating the ore by differential flotation.

In 1926 the American Metal Company, Limited, the present owners, purchased the property. The greatest development and production was begun and has been carried on by this company. Modern equipment has been installed, a new mill erected and a twelve-mile aerial tramway has been constructed. The program of mining and development since then has been carried on in a vigorous and efficient manner.

Access to the ore bodies is gained through two vertical shafts. The Evangeline, located approximately in the center of the mine, was sunk in the more massive diabase between the two principal ore bodies to a depth of 1,060 feet. The Katydid shaft, located to the northeast of the Evangeline shaft, is reached through a tunnel from the surface and extends to the 600 level.

At the present time eight levels, at 100-foot intervals are used for stoping operations. The 900 and 1000 levels have been driven from the Evangeline shaft along the strike of the main shear zone to intercept ore previously encountered on these levels by diamond drilling. Crosscuts are driven at intervals along the main drifts in order to fully develop the shear zone. An extensive program of diamond drilling is carried on continuously in order to prospect ground farther away from the immediate shear zone. Workings extend along the strike of the shear zone for approximately 2,000 feet, and sufficient ore reserves have been blocked out to insure production for a number of years.

No records are available on the production of the mine before its operation by the American Metal Company. For the three years that this company has been operating, however, a total of 584,158 tons of ore have been produced having an average content of 16.06% zinc; 3.73% lead; 1.02% copper; 3.39 ounces of silver and 0.109 ounce of gold per ton. This includes all production up to January, 1930.

Previous Geologic Work and Scope of Present Study.—The earliest record of the geology of the Pecos Mine (then the Hamilton Mine) is by Lindgren and Graton.[1] In this study no attempt

[1] Lindgren, W. and Graton, L. C.: "A Reconnaissance of the Mineral Deposits of New Mexico." U. S. Geol. Surv., Bull. 285, pp. 74–86, 1906.

was made to give a detailed description of the geology of the mine. It served as a basis, however, for a more extended study of the mineral deposits of New Mexico in 1910 by Lindgren, Graton and Gordon,[2] in which the general features of the Pecos district are discussed. An interesting account by Hubbell [3] gives an excellent description of the mine and presents the views of Prescott [4] regarding the origin of the ore deposit and the significance of some of the structural features.

The present paper is intended to present primarily the results of co-ordinated field and microscopic study dealing with the character of the ore, its origin and structural relations. It lays greater emphasis on the details of mineralization, structural characteristics and relationship of the ore deposit to the surrounding country rock.

The field work of the present study occupied the summer of 1930, and was followed by a petrologic study of a selected suite of representative specimens. Although the greater part of this work was confined to the mine itself, the investigation included a reconnaissance of an area of about 25 square miles in the immediate vicinity of the mine.

Acknowledgments.—The officials and staff of the American Metal Company of New Mexico have shown extreme courtesy in assisting the progress of the work. Opportunity was offered to make a detailed study of the mine, and the use of mine maps and equipment was freely given. The utmost hospitality was shown while at the property. Mr. Van Dyne Howbert, Mr. J. T. Matson, Mr. Charles E. Stott, Mr. C. Hoag and Mr. C. E. Anderson of the American Metal Company of New Mexico gave freely of their time and advice and offered many valuable suggestions as the work progressed.

The study on which the present work is based has been carried on under the direction of Dr. Charles P. Berkey, Professor of

[2] Lindgren, W., Graton, L. C. and Gordon, C. H.: "The Ore Deposits of New Mexico." U. S. Geol. Surv. Prof. Paper 68, 1910.

[3] Hubbell, A. H.: "Pecos Mine: A New Zinc-Lead Project." Eng. and Min. Jour., vol. 122, no. 26, pp. 1004–1009, 1926.

[4] Prescott, Basil: Private report.

Geology, Columbia University, to whom sincere appreciation is extended for his friendly advice and criticism, and the benefit of his wide experience in problems of this type. While the field work was being carried on a visit to the property by Dr. Paul F. Kerr aided materially in the interpretation of the field evidence. Thanks are also due for helpful guidance in the preparation of the manuscript. The author is indebted to Professors Roy J. Colony and William M. Agar for their valuable aid in the petrographic study and interpretation.

GEOLOGY OF THE PECOS DISTRICT.

Relief and Drainage.—About 20 miles south of Taos, New Mexico, the Rocky Mountains split to form two main ranges. The ranges extend southward in the form of a broad V and plunge below later sediments near the cities of Santa Fe and Las Vegas, names also applied locally to the two mountain ranges. The Pecos district, which lies between these two ranges, thus falls between two prongs of the broad uplift of the Colorado Plateau. The two prongs form the southern extension of the Sangre de Cristo Range described by Melton[5] as a part of the Ancestral Rocky Mountains of Colorado and New Mexico.

Topographically, all of the region north of Glorieta forms a series of high ridges and mesas through which the Pecos River and its tributaries have cut deep, and in places, box-like canyons. West of the Pecos River, in the vicinity of the mine, the mountains rise abruptly from an elevation of 7,800 feet at the river level to 10,000 and 11,000 feet in the higher portions of the Santa Fe Range. They reach their greatest height in the vicinity of Baldy Peak, which has an elevation of 12,623 feet. On the eastern side, toward the Las Vegas Range, the rise is less abrupt, although to equally high elevations. This may be accounted for by the geologic structure of the region, with its gentle dip to the west. In places drainage channels have migrated down the dip of the sediments and the old pre-Cambrian surface, leaving broad

[5] Melton, F. A.: "The Ancestral Rocky Mountains of Colorado and New Mexico." *Jour. Geol.*, vol. 33, no. 1, pp. 84–89, 1925.

flat areas along the east side of the river which now form excellent grazing and farm land.

The Pecos River, the principal stream of the district, heads about 15 miles north of the mine and flows south and southwest through New Mexico and Texas until it finally empties into the Rio Grande near the Mexican Border.

Geologic Formations and Their Distribution.—The geologic formations of the Pecos district can be referred to two large divisions, the old pre-Cambrian crystalline rocks and the Pennsylvanian sediments. The pre-Cambrian rocks consist of diabase, granite, schists and related types of rocks which make up the backbone of the Rocky Mountains throughout their southern extent. They form the basement floor on which later sediments were laid down, and can themselves be divided into units representing different periods of igneous activity and dynamic disturbance.

An unconformity between the overlying sediments and the pre-Cambrian rocks represents a great interval of time during which the older rocks were worn down to a peneplaned surface. On this smooth surface sediments of Pennsylvanian age were deposited. They are made up of alternating beds of limestone, sandstone and arkose that have an estimated thickness of about 1500 feet.

The pre-Cambrian rocks of the district are well exposed in all the canyons east of the Pecos River and for several miles along the Pecos River north of the mine. A small exposure also occurs about two miles south of the mine at the mouth of Holy Ghost Creek. The dip of the old pre-Cambrian surface, with the overlying Pennsylvanian sediments, is from 7–12 degrees to the southwest. The contact between the pre-Cambrian and the Pennsylvanian intersects the Pecos Canyon slightly below the water level south of the mine. Thus, for some distance along the Pecos River, and in all the canyons immediately to the west of the river, within the area mapped, it is concealed from view by the overlying sediments. The best exposures are found along Willow Creek and Mora Creek.

Upstream from the mouth of Willow Creek the pre-Cambrian

rocks may be traced almost to the head of the stream. An outcrop of siliceous rock, more resistant to erosion than the surrounding schist, stands out prominently at the surface directly above the mine workings. The schist appears to grade into a diabasic rock farther up the canyon. About a mile and a half east of the mine the diabase is intruded by a medium-textured granite which stands out as a prominent bluff above the river.

The exposures in the canyon of Mora Creek consist of diabase which has been intruded by numerous aplitic and pegmatitic dikes, believed to represent the end-stage crystallization products of the granite magma. Similar exposures are found along the Pecos River north of the mine. Here, also, occur numerous dikes, which range in size from a few inches to more than 30 feet in width.

Davis Canyon shows similar exposures to those seen along Willow Creek. A variety of rocks, ranging from altered diabasic and granitic types and their syntectic products, to a series of metamorphic schists, can be seen. The more acid rocks and their syntectic products are believed to represent phases of the same granitic intrusion. The schists are believed to be the product of the same dynamo-metamorphism which was responsible for the development of the shear zone.

Small local shear zones occur along both Willow Creek and Davis Creek. These generally conform in strike to the main shear zone of the mine. The remainder of the area mapped con-

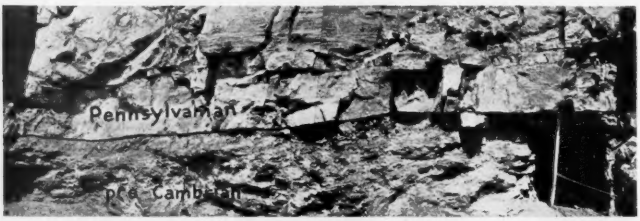

FIG. 2. Photograph showing the unconformable contact between the pre-Cambrian crystalline schists and the overlying Pennsylvanian sediments. Note the gently undulating dip of the old pre-Cambrian surface.

sists of the Pennsylvanian sediments which lie unconformably on the pre-Cambrian. An excellent exposure of the unconformity may be seen at the mine (Fig. 2). An areal map shows the distribution of the pre-Cambrian rocks and the Pennsylvanian sediments (Fig. 3).

As the mineralization at the mine is confined to the pre-Cam-

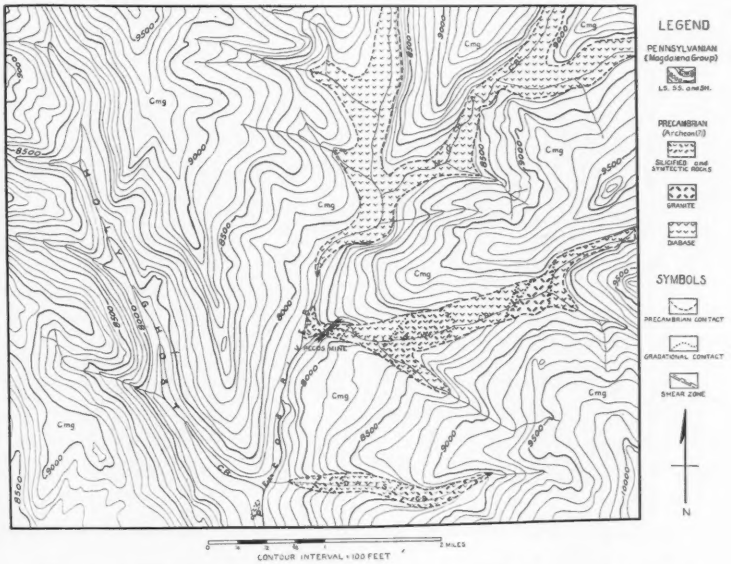

FIG 3. Areal map showing distribution of pre-Cambrian rocks and Pennsylvanian sediments in vicinity of mine.

brian rocks, only these are considered in the following petrologic studies. The sedimentary rocks have been described by a number of writers and sections along the Pecos River have been recorded by Darton [6] and Gardner.[7]

[6] Darton, N. H.: "Red Beds and Associated Formations in New Mexico." U. S. Geol. Surv., Bull. 794, pp. 255–256, 1928.

[7] Gardner, J. H.: "Isolated Coal Fields in Santa Fe and San Miguel Counties, New Mexico." U. S. Geol. Surv., Bull. 381, pp. 449–451, 1910.

PETROLOGIC STUDIES.

The pre-Cambrian rocks closely related to the mineralization at the Pecos Mine consist of diabase, the oldest rock of which any evidence was to be found in this district; and granite, younger than the diabase and intruded into it. Syntectic rocks were developed as a consequence of the intrusion by the granite. This occurred as a result of the infusion of diabasic material within the granite mass. A variety of schistose rocks were developed as a result of the dynamic disturbance accompanying the intrusion. These range from simple biotite schists to quartz-sericite, chlorite and actinolite schists.

Diabase.—The largest single formational unit of pre-Cambrian rock within the area examined is a diabase which outcrops all along the canyon of the Pecos River north of the mine, along Mora Creek, and in a number of places along Willow Creek and Davis Creek. In some places, particularly along Willow Creek and Davis Creek, the diabase grades into mixed granitic types which are believed to represent syntectic products, produced by the intrusion and intimate mixing of granitic magma and its end-stage products with the original diabase. These syntectic products will be described separately.

A number of varietal facies of the diabase occur. Within the area studied, no rocks were found which had not been affected, to some extent at least, by the invading granite mass or its end-stage products. The original rock itself was variable in texture, and to a lesser degree in its mineral composition. Some facies resemble a fine-grained dolerite which originally carried an abundance of pyroxene that has now been completely uralitized, while other facies are coarse-textured and carry orthotectic hornblende as the principal ferro-magnesian mineral.

Megascopically, the diabase is a medium-textured, massive dark rock that weathers dark gray or nearly black. In thin section the rock shows good diabasic structure. Hornblende is one of the principal ferro-magnesian components, in some extreme cases constituting 60–70 per cent. of the rock. It is deep bluish-green, occurring usually in imperfect crystals as much as 2 mm. in length.

The crystals are rarely idiomorphic. The principal feldspar comes within the oligoclase-andesine range. Some of the feldspars show slight zoning, the cores being slightly more calcic than the outer margins. The feldspar crystals are usually ragged in outline and appear to have been affected by the introduction and attack of aqueo-igneous solutions from the granite magma. This attack is manifested in the irregular outlines of feldspar phenocrysts, in which the outer borders are replaced by a more sodic feldspar, and by the development of sericite from the older

FIG. 4. An outcrop of the diabase showing the manner in which it has been injected by granitic material. The black areas are diabase; the white areas are granitic material in which some of the diabase has become assimilated.

feldspar. A deep brown biotite, a metamorphic product of the hornblende, occurs in small flakes intimately associated with the hornblende. Accessory minerals, apatite, titanite, magnetite, and zircon, are distributed irregularly throughout the rock and probably belong to the normal orthotectic minerals of the diabase.

The moth-eaten appearance of most of the principal minerals of the rock; the production of a large variety of secondary products such as sericite, epidote, zoisite, uralite, saussurite, chlorite, biotite

and leucoxene; the interstitial character of most of the quartz and the attack and replacement along the margins of the feldspars, all together strongly support the idea of profound alteration as the result of flooding and attack by the aqueo-igneous emanations of some invading or underlying magma.

Varietal facies of the diabase are numerous along Willow Creek and Davis Creek. They occur abundantly in the mine and have all been affected to some degree by magmatic emanations. In the mine and the near vicinity, alteration has been more intense, resulting in a larger variety of rocks. Some have been completely silicified; others have been so greatly altered that their original nature can only be inferred from the character of their alteration products. Uralite, judged to have been derived from original pyroxene, is one of the most prominent of the secondary products. Still others show such extreme chloritization that only remnants or faint outlines of the original minerals remain. Nearly all of them show addition of quartz and feldspar together with the development of zoisite, epidote, sericite and saussurite. Although initially the diabase had a considerable range in texture, and although it has been altered with variable intensity, the different facies form a reasonably constant petrographic unit distinguishable under the microscope.

The diabase is judged to be the oldest recognizable rock unit in the district. It may have constituted a thick sill intruded into still older pre-Cambrian sediments which are now either entirely destroyed or hidden from view by overlying Pennsylvanian sediments. During pre-Cambrian time, the diabase was caught up in and intruded by a granite. The effect of the granite intrusion is undoubtedly responsible for the profound changes that have taken place in the diabase. It is thought that the diabase may now represent a roof pendant within the granite that has been exposed to permeation and flooding by aqueo-igneous solutions and gases from the granite mass. During the end-stage crystallization period of the granite intrusion, the mineralizers responsible for the metallization within the shear zone were produced.

The Granite.—A steep bluff with a large talus accumulation of rectangular blocks of rock, located about a mile and a half east of

the mine, offers an excellent exposure of the granite. It also outcrops at the head of Davis Creek and in a number of places to the south and west of the immediate area.

The normal granite is massive and uniform in its medium-grained crystalline texture. A flesh-colored orthoclase gives the rock a decided pinkish tinge.

Microscopic examination shows the granite to be holocrystalline and typically medium granitoid in texture, made up mainly of allotriomorphic crystals ranging up to 4 mm. in size. The small quantity of ferro-magnesian minerals in the granite is a striking feature. Biotite is present in only minute amounts. From its interstitial position and its distribution along the margins of quartz and feldspars, it does not appear to have been derived from the normal crystallization of the magma, but is probably a product of assimilation of the older diabase. The biotite is usually associated with quartz and albite.

The granite consists largely of soda-microcline, quartz, orthoclase, perthite and albite. Titanite, magnetite, and muscovite are minor accessory minerals. The orthoclase commonly occurs as idiomorphic phenocrysts 2 to 4 mm. in length, somewhat modified by the attack of end-stage crystallization residuum which brought about the development of sericite and very fine aggregates of kaolinitic material. Carlsbad twinning is prominent. Some of the crystals are traversed by microscopic quartz-filled cracks. Microcline is one of the most prominent constituents of the granite. It is especially interesting because it shows a tendency toward poikilitic development. It was probably one of the last of the orthotectic minerals to crystallize, for in many instances it completely incloses earlier-formed crystals of orthoclase and quartz. Irregular masses of microcline are also distributed interstitially, and in some places it is intimately mixed with fine aggregates of quartz and albite. In some instances albite has penetrated the microcline and orthoclase, producing a perthitic appearance. As the microcline was one of the later minerals to crystallize, and as it may itself have been one of the end-stage components, it has escaped deuteric attack, whereas the orthoclase was considerably affected.

The quartz of the granite exists not only in large unit areas, but it also is distributed interstitially, intimately associated with albite and microcline. It may contain characteristic fluid cavities common to rocks of this type. Albite, with quartz and probably microcline also, is one of the final consolidation residua of the granite magma and is in part responsible for the slight deuteric attack on the normal orthotectic minerals of the rock. The attack on the granite is not so intense as that which affected the diabase. This may have been because the granite was in more stable equilibrium with its own end-stage products, whereas the diabase was compelled to undergo greater reorganization upon the invasion of the granitic material. Alteration products of the granite consist of sericite, muscovite, kaolinite, leucoxene and a small amount of epidote and saussurite. The granite is quite fresh in appearance and has not been greatly affected by superficial weathering agencies.

Relation of the Granite to the Diabase.—The granite is intrusive into the diabase. Good evidence of this is to be found in the outcrops along Willow Creek and at the head of Davis Creek. Small dikes and stringers of the granite cut the diabase, many of which can be traced directly back to the granite mass. A comparison of the mineral components of the granite with those of the granite dikes which are intruded into the diabase shows a marked similarity in composition. The suites of minerals in both the main body of the granite and in the invading granitic dikes are rich in soda-microcline, quartz and albite.

Syntectic Products.—In the vicinity of the granite intrusion, particularly along Willow Creek and Davis Creek, a variety of syntectic products have been developed. They are products of the intimate mixing and assimilation of the diabase with the invading granite magma and its late-stage crystallization products. The minerals of the older diabase have been attacked and reorganized so that in some cases only remnants are left, or recrystallization has taken place so that minerals of the older diabase have been greatly altered. Most of the syntectic products differ in appearance from the normal granite or diabase, and from their light color they have been referred to at the mine only as a more " acid

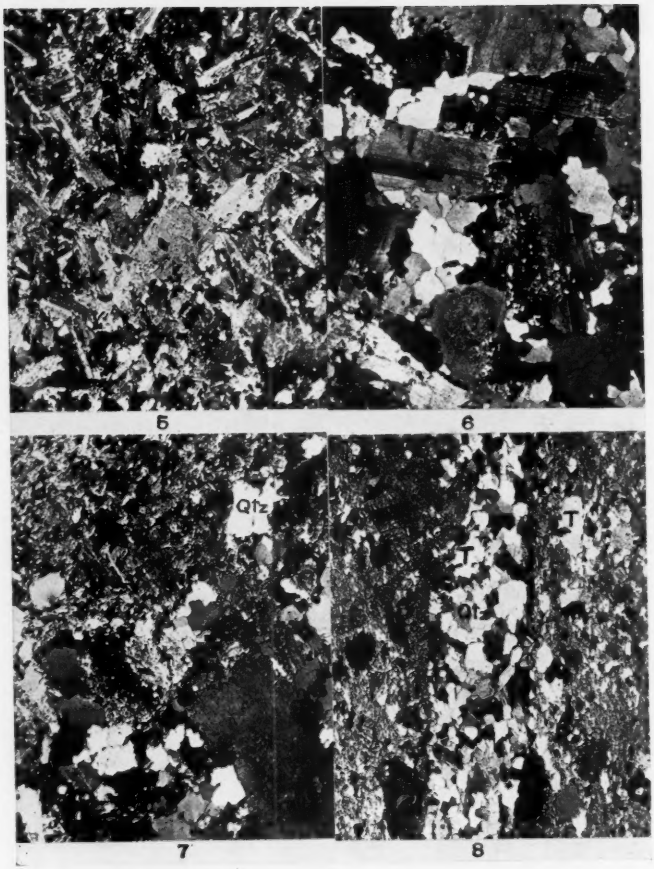

FIG. 5. Thin section of the diabase showing the structure and the manner in which the minerals have been modified by the end-stage constituents of the granite. × 20.

FIG. 6. Thin section of the granite, showing the structure and mineral composition. A rounded crystal of orthoclase has been partially altered to sericite with the addition of more sodic feldspar around its outer margin. × 15.

FIG. 7. Thin section of one of the syntectic rocks, showing the masses of uralite (*Ur*) formed from original ferro-magnesian minerals of the diabase, and the interstitial character of the quartz (*Qtz*). × 15.

FIG. 8. Thin section of quartz-sericite schist, penetrated by quartz (*Qtz*) veinlet and tourmaline (*T*). × 15.

rock." They vary in texture and structure. The coarser varieties, such as some of the specimens taken from the upper end of Davis Canyon, more nearly resemble the granite in a hand specimen. The rocks from this vicinity also show an abundance of quartz and soda feldspar, as though the invading material had been particularly rich in these components. Remnants of minerals believed to have been a part of the original diabase are present. They may usually be distinguished by their greater alteration and by the manner in which they have been completely surrounded with, and partially assimilated by the invading granite mass. The original ferro-magnesian minerals of the diabase have been highly altered by this process. A deep brown biotite has been developed from hornblende and now occupies mainly an interstitial position between minerals of the granite, and is intimately associated with uralite. Muscovite and sericite have been formed as alteration products of the feldspars.

A specimen (S–38) from Davis Canyon shows a coarsely crystalline mixture, somewhat resembling material from the pegmatite dikes of the region. Caught up within it, however, are patches of the material from the diabase that have been almost completely assimilated or digested by the granite magma. Irregular outlines of feldspar crystals occur, their center portions composed of highly altered and partially assimilated feldspar of the diabase, whereas the outer portions consist of alkali feldspar of the granite that has attacked and replaced part of the older mineral.

Myrmekite-like intergrowths, similar to those described by Sederholm,[8] occur abundantly. These are usually intergrowths of quartz and orthoclase and are not the true intergrowths of myrmekite of Sederholm, which are of quartz and plagioclase feldspar. Patches of acicular, bluish-green amphibole (uralite) are common in the syntectic rocks. These have also been partially assimilated by the granite magma, and their edges usually show fine aggregates of quartz and feldspar, and they are often intimately intergrown with quartz. Although the patches of

[8] Sederholm, J. J.: "On Synantetic Minerals and Related Phenomena." Bull. Geol. de Finlande, No. 48, 1916.

partially assimilated uralite and highly altered feldspar are believed to represent minerals of the older diabase, the percentage of these minerals in the syntectic rocks is not great and most of the rocks are made up of the normal minerals of the granite.

Quite a different variety of syntectic rock occurs in places along Willow Creek. It is finer in texture and is made up mainly of granular quartz and feldspar. Occasionally larger phenocrysts of feldspar occur; their borders present a ragged and moth-eaten appearance, and they are traversed by microscopic fractures which are filled with small flakes of brown biotite. The feldspar phenocrysts are usually surrounded by fine aggregates of quartz, feldspar and biotite, and they exhibit the effect of partial assimilation and recrystallization. Muscovite is a common alteration product of the feldspars. Irregular patches of the finely crystalline mixed aggregates also occur as individual units. These are also believed to represent minerals of the diabase that have suffered attack, partial assimilation and recrystallization by the intrusion of the granite. Myrmekite-like intergrowths are also common in this variety. The quartz of the granitic material occurs as larger euhedral crystals, often enclosing masses of the recrystallized or highly altered aggregates of mixed minerals of the diabase.

Still another variety is made up almost entirely of recrystallized quartz and feldspar. If it were not for the occasional larger phenocrysts of feldspar and the presence of small flakes of biotite or chlorite in irregular aggregates, the rock would closely resemble a quartzite that had been metamorphosed sufficiently to cause recrystallization. That the rock has been affected by some deformation is evident in the undulatory extinction shown by most of the quartz grains. Some of the quartz was introduced after most of the reorganization had been effected and now occupies small veinlets within the mass.

The diversity in mineral composition, texture and structure of these syntectic rocks is believed to be due to variation in the intensity of attack by the granite; the degree to which the diabase has become assimilated; and to movement affecting the rocks after invasion had taken place. They appear to grade from the

normal granite to the diabase. Isolated blocks of the diabase, however, occur in places within the areas of syntectic rocks. They appear to have been caught up bodily within the magma and show the effect of the granite intrusion only around their margins. Good exposures of these are to be seen along Willow Creek and Davis Creek.

The Schists.—Where dynamic movement and deformation in the zone of weakness of the diabase has taken place, with the development of a sheared zone, a variety of schistose rocks have been developed. Most of the underground workings of the mine are confined to this zone and here, except for the relatively unaffected masses of diabase, the rocks are all of a schistose nature. Deformation within the shear zone has not been uniform, and the schists themselves vary in mineral composition as well as in the degree to which they have been affected by dynamo-metamorphism.

Most of the schistose rocks are judged to have been derived from granitic material or the more acid segregations of the granite magma that was intruded into the zone of weakness before deformation took place. The rocks are mainly quartz-sericite schists with only minor amounts of chlorite and biotite. Other varieties are judged to have been derived from a mixture of granitic material with the diabase. These show an abundance of both sericite and chlorite as well as schistose quartz, all arranged in a foliate manner. A simpler variety, produced from the shearing of the diabase, shows a preponderance of biotite with only a small amount of chlorite, quartz and sericite.

Quartz-Sericite Schist.—The quartz-sericite schist is widely distributed throughout the mine, and is encountered in most of the drill holes away from the more strongly mineralized areas. In a hand specimen it shows a fine granular or sugary texture. The schistose structure is not always prominent, but if the rock is examined with a hand lens the orientation of the mica flakes is readily seen.

In thin section the schistose structure of the rock is brought out prominently. Quartz is by far the most abundant mineral and makes up the greater part of the rock. Sericite is next in

abundance and only minor amounts of chlorite or biotite are present. There is a variety of textures even in a single slide. Patches of fine-grained, mixed schistose quartz and sericite show good evidence of shearing and granulation. These patches of fine-grained material commonly serve as a matrix for larger unit areas of clear quartz, much coarser in texture than the matrix and sometimes fractured, with inclusions of finer quartz and sericite. Small veinlets of introduced quartz may follow the foliation planes of the rock and were evidently introduced after most of the shearing had taken place.

The rock is a good example of a schist developed through the shearing and granulation of a granite or granite pegmatite. The areas of coarser quartz are believed to be original quartz of the granite; the finer masses of mixed quartz and sericite, with a decided schistose structure, are derived from the shearing and granulation of the feldspars and the finer-grained quartz. In some of the unsheared granites and the more acid syntectic rocks, poikilitic intergrowths are common. It is thought that the finest mixed patches of quartz and sericite occurring in the schists may represent areas of these intergrowths that have been much sheared and granulated. All three textures may be seen in the same field under the microscope.

Quartz-Chlorite Schist.—Another variety of schistose rock that occurs in abundance within the shear zone is a mottled, greenish, fine-grained rock that is essentially a quartz-chlorite schist. It is found in the areas of greatest disturbance and along the walls where movement has taken place. Much of the metallization appears to be associated with this type of rock, and for this reason it may be of importance from the standpoint of ore localization.

In thin section the rock is strongly schistose. It is composed mainly of quartz, chlorite and sericite, all oriented in the same direction. The quartz grains may be slightly elongated and have an average size of about 1 mm. The sericite is intimately associated with the quartz, but rare patches occur that consist almost entirely of sericite. These patches probably represent feldspar crystals that have been completely altered. A peculiar feature of the rock is the distribution of large, prominent patches of chlorite

that may show a parallel intergrowth of muscovite and biotite. The origin of the chloritic patches in the rock is obscure. They are believed to have been derived from the ferro-magnesian minerals of the diabase, and it is judged that the rock itself was originally a mixed one; a product of assimilation and intimate mixing of some of the diabase with the invading granitic material. With the advent of shearing, a mottled, patchy, schistose rock was developed that appears to have been particularly susceptible to mineralization.

Biotite Schist.—Where shearing has taken place around the outer margins of isolated blocks of diabase, a black, biotite schist has been developed. This type of schist consists mainly of biotite with only minor amounts of quartz and sericite. The biotite may be slightly altered to chlorite. The biotite is a metamorphic product derived from the ferro-magnesian minerals of the diabase during the dynamic movement that was responsible for the shear zone.

All the schistose rocks vary in the degree to which they have been affected by dynamo-metamorphism. Where definite planes along which movement has taken place can be seen, "talcy" schistose gouge is present. If the movement has been post-mineralization, ore has often been caught up with the gouge and has been dragged along the plane of movement.

(*To be concluded in next number.*)

PROSPECTING FOR "OIL" IN AUSTRALIA AND NEW GUINEA.[1] PART I.

E. C. ANDREWS.

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INTRODUCTION.

IN 1924 a note [2] was published in this Journal on the status of the search for petroleum in Australia.

The present note brings the information on this matter to date, and it has been written in the belief that it affords an explanation, in some measure, of the inability, in the past and even at the present day, to discover commercial supplies of natural oil in Australia.

The evidence adduced in the earlier note mentioned above was

[1] The present note is a continuation of the 1924 report on the same subject to ECONOMIC GEOLOGY.

[2] Andrews, E. C.: Prospecting for Petroleum in Australia. ECON. GEOL., vol. 19, pp. 157–168, 1924.

such as to indicate that the pioneer prospectors of Australia were the worthy contemporaries of the men who discovered mineral deposits of importance elsewhere. History speaks eloquently of their methods and of the results of their search.

The accompanying notes indicate:

(i) The nature, the amount, and the results of the main prospecting ventures for "oil" in Australia, Papua, and the Mandated Territory of New Guinea during recent years.
(ii) The general significance of this prospecting work.

Acknowledgments.—Indebtedness is expressed to those who have assisted materially in the preparation of this paper: to H. G. Raggatt of the Geological Survey Staff of New South Wales for the preparation of the notes on New South Wales and the notes on New Guinea, to L. K. Ward, T. Blatchford, L. C. Ball, W. R. Baragwanath, and P. B. Nye, State Geologists of South Australia, Western Australia, Queensland, Victoria, and Tasmania respectively, for information and for State maps indicating the approximate positions of the main prospecting sites. Information also has been supplied by L. J. Jones of the Geological Survey of New South Wales, who led an "oil" prospecting expedition across the Desert Basin of Western Australia in 1922. The information also contained in the reports of F. G. Clapp [3] and Arthur Wade [4] has been of great assistance in the preparation of the present condensed report of prospecting activities for natural oil.

No boring of importance appears to have been conducted within Federal Territory (North Australia, Central Australia, Federal Capital Territory) on the mainland, although much geological surveying, together with boring, has been conducted within Papua, the Mandated Territory of New Guinea, and the associated areas, both by the Commonwealth (Federal) Government and by private interests. The Commonwealth Geologist, Dr. W. G. Woolnough, has quite recently visited many of the principal North and South American "oil" fields, in order that the Federal

[3] The Oil Problem in Western Australia. Econ. Geol., pp. 409–430, 1926.

[4] Petroleum Prospects, Kimberley . . . and Northern Territory, pp. 10–26. By authority. October, 1922.

authorities may be in a position to understand the "oil" position in Australia. The Commonwealth Geologist at present is investigating certain "structures" in the Wooramel (Western Australia), Mount Gambier (South Australia), Lakes Entrance (Victoria), Longreach (Queensland), and other, areas in regard to their possible "oil" prospects.

"OIL" PROSPECTING IN THE VARIOUS STATES.

Victoria (Notes by W. R. Baragwanath).

The amount of money which can be accounted for in the main oil prospecting ventures is £173,000, the amount unaccounted for, say £27,000, making a total of £200,000.

Chief interest attaches to the Gippsland area where, in the vicinity of Lakes Entrance, some 26 bores have been sunk at an approximate cost of £50,000. Sixteen bores obtained oil ranging from 5 gal. to 200 gal. per day by pumping, but efforts have not been continuous. Up to the time of writing, 12,500 gallons have been obtained. The oil is confined to a bed of glauconite of Oligocene age which rests on the bedrock (Granite and Ordovician). A typical section of the strata in Lakes Entrance district is:

	Ft.
Sand, shelly and granular limestone (Kalimnan, Pliocene)	140
Polyzoal limestones and marls (Janjukian, Miocene)	1,000
Ligneous and micaceous marls with several hard bands of limestone (Oligocene)	220

The oil is heavy. Specific gravity, .961; contains no light fractions. Initial boiling point 265° C. Gas oil, 230–300°, 13%. Heavy oil, over 300° C., 87%. Bitumen base.

Other bores have been put down near Traralgon (1830 ft. in lignites and clays), at Port Addis, Torquay, Glenelg River (near Munbannar), and Comaum in the Tertiary series.

Tasmania (Notes by P. B. Nye).

No record has been kept of expenditure on boring in Tasmania and it is difficult to ascertain the amount, so that the following figures are approximate only.

Surface Prospecting.—Interest has been directed to many parts of the State mainly in connection with discoveries of asphaltum, cannel coal, pelionite, and other hydro-carbons. Such localities include Port Davy, New River, King Island, Barn Bluff, Macquarie Harbour, Bruni Island, and the Mersey Valley. Generally speaking, prospecting has resolved itself into the pegging of licenses or leases, collection of samples, and in a few cases geological reports have been obtained. The expenditure in this manner has been small and probably does not exceed £10,000–£20,000.

Drilling.—The only locality where any extensive amount of drilling has been carried out is in the Mersey Valley district. The Mersey Valley Oil Co. Ltd. drilled 9 holes (total depth 5,781 feet) and a 10 inch "well." Apparently about £50,000 has been spent.

The Adelaide Oil Exploration Co. has drilled at least 12 holes with an aggregate depth of 8,507 feet. The expenditure by this company in Tasmania can only be estimated as between £20,000 and £40,000.

On Bruni Island one hole was drilled to 430 feet depth in 1915. Several shallow holes were drilled last year.

In round figures it would appear, therefore, that the expenditure on oil prospecting (surface work, drilling, and so on) has not exceeded £100,000.

No "oil" has been discovered within the State.

South Australia (*By L. K. Ward*).

I cannot say how much money has been spent on the search for oil in this State, but it must be very large. Assuming that the information supplied is correct the total footage bored is at least 26,856 ft. The South Australian Oil Wells Co. has itself spent a sum that cannot be far short of £100,000 on work in this State. Probably it is much more.

I have stated many times that, in my considered opinion, no appreciable and unquestionable sign of oil has been seen as a result of all this boring.

Many years ago Cosmo Newbery found a trace of free oil in shale from Leigh Creek, but the hole was continued into bedrock without any more being recognized. Later borings in this district afforded no trace of oil.

A well-defined anticlinal structure has been discovered within a few miles of Mount Gambier, and the area concerned in the folding has been mapped geologically. Such a structure, if discovered in a region that had been proved to be petroliferous, would justify a boring campaign. However, it still remains to be shown that any oil exists in this part of Australia. The nearest occurrence of oil is 400 miles away from Mount Gambier, and the intervening Tertiary rocks have not yet afforded successful results, even though boring has been carried out where structural features have been considered favorable. No unquestionable seepage of oil has been located in South Australian territory. It is, therefore, impossible to assess in quantitative terms the degree of the risk involved in boring on the anticlinal structure near Mount Gambier.[5]

The rocks of the Tertiary system in this region are not unfavorable for the existence of commercial accumulations of oil. as regards either age or lithological character.

The first question to be decided is that concerned with the advisability of boring for oil in a region where favorable structural and lithological conditions are present, but in which no satisfactory evidence has been adduced of the existence of even traces of natural oil, in the form of seepages or as the result of drilling operations. There is a great risk of failure to obtain appreciable quantities of petroleum in any borehole in this region. Comparisons of the strata with those of proved petroliferous regions have only a limited value.[6]

My conclusions, therefore, are: (1) I cannot say how much has been spent on prospecting for oil in this State. (2) No genuine oil has been obtained from any natural seepage or from any borehole drilled hitherto in any part of South Australia. Bitumen has been found on the beaches along the whole shore line, where

[5] Mining Review, So. Australia, No. 53, pp. 58–59.

[6] *Idem*, No. 53, p. 91.

pre-Cambrian and Tertiary rocks alike reach the sea. Fuel oil, from motor ships, has been washed ashore at Victor Harbour, Kangaroo Island, Normanville, Noarlunga, and other places. Marsh gas has been observed by those who have probed in swamps, river muds, and places where seaweed is buried beneath beach sand.

Western Australia (By T. Blatchford).

Mr. Blatchford [7] states:

The conclusions arrived at are that mineral oil has occurred in considerable quantities in the beds underlying the basalt flows of the Ord River Basin, and that some, at least, of this oil has escaped through a line of weakness and formed the bitumen now found near Texas Homestead and the Negri River. There is also definite evidence of mineral oil in the lower beds of the Lower Carboniferous limestones at Price's Creek, and in the beds pierced at the Mt. Wynne bore. There is no doubt as to the presence of beds sufficiently porous to store oil. The evidence of suitable cover rocks is not altogether satisfactory. Shale beds of considerable thickness are exposed at Flora Valley in the Lower Cambrian Series, and suitable shale beds are also found in the Negri beds overlying the basalt flows. In the bores in the Carboniferous rocks at Mt. Wynne and 67-Mile, narrow shale beds were cut, and at Mt. Wynne compact mudstones of considerable thickness. There is, however, a paucity of shale beds when compared with the thickness of the limestones and sandstones. The small traces of mineral oil in the Mt. Wynne bore and at Price's Creek, and the total absence of oil seepages along any of the fault lines in the three structures at the Grant Range, Mt. Wynne and Poole Range suggest the presence of cover rocks, but are by no means conclusive evidence of such.

There is little, if any doubt that several suitable structures exist, and though faults exist in each, the other conditions are favorable. The dips of the rocks are low, the structures are closed on all sides, and there is no evidence at the surface of oil seepage. To prove whether oil actually does exist necessitates boring. Two attempts have already been made, one at Mt. Wynne, the other in the Ord River Basin. At Mt. Wynne, owing to drilling difficulties, the hole was abandoned at a depth of some 2400 feet without the oil-bearing beds being tested. The Ord River bore was shut down before reaching the bottom of the basalt beds. No oil was found in the Negri beds overlying the basalt.

Before it can be definitely decided by boring whether oil exists in the

[7] Blatchford, T.: Geology of Portions of the Kimberley . . . occurrence of Mineral Oil. Geol. Survey, Western Australia, Bull. 93, pp. 46–47.

Fitzroy beds, it should be realized that it may be necessary for the hole to be carried to a depth of at least 4000 feet, possibly 5000 feet. Oil may be struck at a lesser depth, but if not, there will be no finality unless the Lower Cambrian strata are reached.

Other bores for oil have been along the Coastal Area and put down to shallow depths only—not exceeding 150 feet.

The following note dealing with the area south of that described in the preceding paragraphs by Blatchford has been supplied by Mr. L. J. Jones [8] of the Geological Survey of New South Wales:

Carboniferous rocks consisting of a lower series of limestone, 1000 feet thick, and an upper series of sandstone and sandy shale 1500 feet thick, occupy a large area south of the Kimberley district, Western Australia. These beds rest unconformably upon Cambrian sediments and in places directly overlie Archaean granite.

At the southern end (Lat. 23° 5) the rocks are for the most part horizontal with occasional local steepening of dips to 5° forming broad folds. Traced northerly and northwesterly, away from the influence of the continental shield, the beds show gradually increasing dips.

Asphaltic residues and traces of oil have been found along the northern outcrop of the lower limestone beds, and it is thought that farther south, where these beds are protected by an adequate cover of Upper Carboniferous rocks, gently flexed and free from intensive faulting and fracturing, there are possibilities that the limestone beds still retain their original oil contents, which may or may not be in appreciable quantities.

Queensland (*By L. C. Ball*).

In Queensland nearly 59,000 ft. of percussion drilling has been done, and 50,000 ft. of rotary drilling, and I think that this probably involved an expenditure of £750,000. Additional allowances of £20,000 might be made for scout boring and well sinking, £20,000 for geophysical survey work, and £5,000 for geological consultations.

Approximately 30,000 gallons of light oil have been won, the greater part from Hospital Hill gas. The yield of the Blythdale and Mount Bassett bores amounted to a few hundred gallons at most, and the Longreach Town Borehole yielded only a few score gallons of oily wax.

[8] L. J. Jones was the leader of a prospecting party which crossed the Great Desert Basin in 1922.

The most definite encouragement comes from the Hospital Hill bores at Roma (300 miles inland from Brisbane), where petroliferous gas is met near the bottom of the Mesozoics at about 3,700 ft. depth, in association with salty water. At slightly greater depths, eleven miles to the east of Blythdale, bores under similar conditions tapped a few gallons of medium grade oil but attempts to shut off the accompanying artesian waters were fruitless. Some ten miles to the north of Roma, medium grade oil was met towards the base of the Mesozoics but all endeavors to induce production have been unavailing.

The evidence to date suggests that the petroliferous gases and light oils at Roma are confined to the coarse-grained clastics mantling the pre-Mesozoic land surface. Gas is said to have issued from one of the earlier bores at Roma at the rate of 20 million cubic feet per day but the later ones gave a maximum of only one million. The petrol content of this gas is from one to two pints per thousand cubic feet. The pressure has been tested to 500 lb.

The oil-bearing wax met in arkose on the old granite land surface at Longreach is not accompanied by gas and endeavors to increase the yield have so far failed. It may be significant, however, that petroliferous gas issues in small amount with water flowing from several of the deeper artesian bores in the Longreach-Winton district, accompanied in a few cases by a paraffin wax.

The petroliferous sediments are believed to be basal Mesozoic and to be terrigenous like the whole of the Triassic and Jurassic of the State, the few thousand feet of which are overlain by a few hundred feet of Cretaceous strata of marine and freshwater origin in places capped by relatively thin Cretaceo-Tertiary lake beds. In none of the sediments above the basal petroliferous zone has any petroleum been found. The basement rocks at Longreach are granite and at Roma are granite and tilted slate regionally metamorphosed and presumably of early Paleozoic age. It has been suggested that the Roma oil and gas may have migrated from the Permo-Carboniferous sediments and some attention has been directed to a major structure of promise that has

been developed in the Springsure area, but evidence of the Permo-Carboniferous rocks being petroliferous is wanting.

Another major structure is known in the Triassics near Brisbane, but this has suffered from igneous intrusion and the carbon ratio of the coals there also is high.

Present operations are confined to geological mapping in the Roma and Longreach districts, to the drilling of one hole in the Roma district, in addition to two others near Brisbane (one on a site selected by divination and one on a site selected by means of a secret instrument).

The position thus remains as heretofore, that we have petroliferous gas and light to medium gravity oils on the basement rocks at Roma and petroliferous gas and oily wax under similar conditions at Longreach, but that structural requirements for accumulation on a commercial scale have not yet been met; and larger structures in the Brisbane Valley and in the Springsure district have not yet given any direct encouragement to deep drilling.

New South Wales (By H. G. Raggatt).

Lower Hunter Valley.—The principal activity in oil and gas prospecting in New South Wales has taken place in the Lower Hunter Valley, where a considerable thickness of Permian [9] beds is developed, including both marine and freshwater rocks. The following table summarizes the stratigraphy of this system and gives the thicknesses of the series commonly developed:

	Thickness in feet
Upper Coal Measures.	
(*a*) Upper or Newcastle Division	1,500
(*b*) Lower or Tomago Division	1,800
Upper Marine Series	
(*a*) Crinoidal Stage	1,500–2,000
(*b*) Muree Stage	200–300
(*c*) Branxton Stage (Fenestella beds 1,300 to 1,650 feet above Greta Measures)	2,200–2,900
Lower or Greta Coal Measures	275–300
Lower Marine Series	4,800

[9] The term "Permian" has been used by the Geological Survey of New South Wales, during the past four or five years, to include all the strata from the top of the Kuttung Series to the base of the Narrabeen. The term is used in the same sense by Walkom (Compte Rendu, XV Int. Geol. Cong. South Africa, 1929, Vol. II, p. 166).

Many anticlinal structures have been noted in the Lower Hunter Valley, including the Lochinvar, Belford, Loder, Sedgefield and Darlington Domes and the Camberwell and Lemington Anticlines.

Lochinvar Dome.—The Lochinvar structure was mapped by Sir Edgeworth David in 1888 and partial closure of structure contours about the Blair Duguid inlier (Kuttung, Carboniferous) has been demonstrated by H. C. Millard.[10].

W. J. Maskell's bore in the Lochinvar Dome commenced in the Lower Marine Series about 500 feet below the Greta Coal Measures, and had reached a depth of 3460 feet at the end of 1930. A sum of £10,000–£12,000 has been expended on boring at this site.

Belford Dome.—Boring was commenced in this anticlinal structure by the Broken Hill Proprietary Company on the advice of J. M. Morris. The bore commenced 200 feet below the Fenestella Shales and penetrated the Greta Coal Measures at a depth of 1460 feet.

Detailed field work by H. C. Millard, verified by Wade [11] demonstrated the existence of a closed structure at this locality, known as the Belford Dome. This feature has been mapped recently in detail by the Geological Survey of New South Wales. The Dome has its principal axis arranged approximately meridionally and is asymmetric normal to this direction. The average dip of the eastern limb is about nine degrees; that of the western limb varies from 14 to 40 deg.

In 1927–1928 Belford Dome Ltd. put down two diamond drill bores, one about a mile northeast, the other about a mile southeast of Belford to depths of 1550 feet and 1664 feet respectively. The Greta seams were proved to be of workable quality and thickness. In each of these and in the Broken Hill Proprietary Company's bore some small outbursts of methane gas were noted. Belford Dome Ltd. in 1929 commenced boring with a cable drill capable of reaching 6000 feet. This bore had reached a depth of 1498 feet at the end of 1930 without yielding other than a small amount of gas.

[10] Wade, A.: Petroleum—Report on investigations made in New South Wales, p. 10, 1925.

[11] *Idem.*, p. 9.

Belford Dome Ltd. have expended a sum of about £48,000, of which £25,000 approximately is represented by the cost of actual boring.

Loder Dome.—The Loder Dome was shown by C. W. Washburne in 1925 to be a closed structure. It has also been mapped in detail by the Geological Survey of New South Wales. The lowest beds exposed by dissection of the dome are approximately 400 feet above the corresponding beds on the Belford Dome.

The bore put down by Oil and Gas Investigations Ltd. in 1926–1927 on this dome passed into the Greta Coal Measures at 1762 feet and into the Lower Marine Series at 2039 feet. It was discontinued at a depth of 2391 feet. Notwithstanding the high expectation by geologists of note that this bore would yield gas in commercial quantities, no marked emanations were noted. The sum expended in connection with prospecting operations on the Loder Dome amounts to £20,000 approximately.

The Sedgefield structure has been shown to consist of two domes side by side. The Darlington Dome was discovered and mapped by the Geological Survey of New South Wales in 1927.

It is not known whether closure can be proved on the Camberwell and Lemington anticlines which are developed in the Upper Coal Measures, thus providing cover in an anticlinal structure over the whole of the marine series. None of these structures has been tested by boring. Some shallow shafts have been sunk in an endeavor to ascertain the dips on the Lemington Anticline between Jerry's Plains and Warkworth.

Other Areas in New South Wales.—Oil and gas prospecting operations carried out in New South Wales prior to 1921 have been well described by Leo J. Jones.[12]

Total sums expended in boring for oil and gas in New South Wales, that can be accounted for, approximate £100,000. The actual cost of oil and gas prospecting operations is in excess of this figure, since there has been prospecting in many localities, the cost of which cannot be estimated reliably. The actual amount

[12] Notes on Petroleum and Natural Gas, and the possibilities of their occurrence in N. S. W. Mineral Resources No. 31, Geol. Survey, N. S. W., 1921, pp. 23–39.

expended probably is equal to that for Victoria, namely £200,000 approximately.

Australia.

W. G. Woolnough, Geological Adviser to the Commonwealth Government, deals also with the prospects [13] of obtaining "oil" in Australia and the Territories. He states:

Of all the geological formations met with in Australia, none is more worthy of serious consideration than the Permo-Carboniferous. . . .

The great basin of Permo-Carboniferous formations extending from the valley of the Hunter River in a northwesterly direction beyond Gunnedah is worthy of research. Its coastward portion has already been examined in considerable detail, on account of the coal measures which it contains, and several promising-looking structures have been sketched, mostly in a preliminary way.[14] . . . Much more investigation of the potentialities of Permo-Carboniferous formations in Queensland and New South Wales is called for.[15] . . .

Upper Mesozoic rocks of marine origin are widespread particularly in Queensland and New South Wales. They have been penetrated by thousands of bores in drilling for water contained in the underlying Walloon (Jurassic) system. In the Roma district this formation is of comparatively insignificant thickness, but in other parts of the State it is much greater. Indications suggest that conditions of deposition were at least not inimical for the genesis of oil, and that small quantities of oily substances are widely distributed in the formation. These Cretaceous marine beds are worthy of more attention than they have received, particularly in those deeper portions of the artesian basin, in which they have been practically neglected.

Tertiary formations in Australia, quite analogous in many ways with those which are the world's great oil producers along the axis of mountain folding, differ from the latter in the extremely important respect that they have not had developed in them the structures which are just as important from the point of view of oil as are the oil-forming conditions. We cannot anticipate on the mainland of Australia any oil-fields of the Californian type. . . .

Although Tertiary rocks are developed along the north coast of Australia, and in Bathurst and Melville Islands, it is along the south

[13] Report on Tour of Inspection of the Oil fields of the United States of America and Argentina, 1931, pp. 85–87. By Authority. Government Printer, Canberra.

[14] Several structures have been mapped in detail by the Geological Survey of N. S Wales, but the results have not been published. (E. C. A.)

[15] See, however, notes on Queensland, by Ball, pp. 371–373.

coast that they reach their maximum development. With important interruptions to their continuity they extend from eastern Gippsland to Esperance in Western Australia, showing a remarkable similarity in types throughout the whole of this extent. Confined for the most part to areas not very distant from the coast, similar rocks are met with for some considerable distance up the valley of the Darling River above its confluence with the Murray. Though they have been very extensively examined, and though quite a good deal of drilling has been done, mostly on very inadequate preliminary work, these Tertiary rocks have proved themselves so far to be almost devoid of those types of structure necessary for the concentration and retention of oil. . . . That, locally at least, they exhibit conditions for oil formation, is conclusively shown by the degree of success which has been attained at Lakes Entrance, Victoria, where small supplies of genuine oil are being obtained from relatively shallow bores. This oil is being derived from a green (glauconitic) sand almost at the bottom of the Tertiary formation, and in close association with artesian and subartesian water. . . .

New Guinea (By H. G. Raggatt).

New Guinea is a large island comparable in size with New South Wales, the area of each being somewhat in excess of 300,000 square miles.

With the exception of some relatively narrow coastal and flood-plain areas, the topography of the island is markedly mountainous. Most of New Guinea is clothed with dense forest, the exceptions being the upper portions of the high alpine ranges that traverse its length, and the "Kunai" or grasslands that occupy large areas in some parts of the island.

Territorially, New Guinea is divisible into three portions. The portion west of the 141st Meridian of East Longitude is Dutch New Guinea; that lying to the east of the meridian is subdivided into southern and northern portions known respectively as Papua and the Mandated Territory (of New Guinea).

Present Status of the Search for Oil.—A considerable amount of rapid reconnaissance work has been conducted in various parts of the island but so far as Papua and the Mandated Territory are concerned, areas totalling less than 1000 square miles have been mapped in detail. Nevertheless much drilling has been done, so far with disappointing results.

Summarizing the latest published work (1920–1929) of the Anglo-Persian Oil Company's geologists, B. K. N. Wyllie, by comparing the New Guinea region with the neighboring producing oil-fields in Sumatra, East Borneo and Burma, concludes, in the first place, that it cannot be expected that oil fields will be found in New Guinea in areas other than those occupied by sediments of lower and pre-Neogene age. In the second place he points out that "In Papua and New Guinea the Neogene terrain has suffered such intense denudation since it was folded that practically all the known anticlines appear to be eroded well below the horizons at which, on the above reasoning, good oil-fields could be expected. . . . One is forced, therefore, to conclude that in the regions of Papua and New Guinea covered by the Anglo-Persian work, major oil fields, if they ever existed, have fallen victims to denudation."

The recent work of Mr. G. A. V. Stanley [16] modifies somewhat Mr. Wyllie's unfavorable estimate of oil prospects in New Guinea, for, so far as Matapau is concerned, he appears to have established:

1. That the area is not affected by overthrusting to anything like the extent postulated (by Nason-Jones).
2. That the plutonic rocks are, in part, older than the oil series, not entirely younger, as hitherto considered.
3. Larger areas are occupied by beds of Neogene age in the Matapau hinterland than has been realized before.

It would appear, as a result of the above, and in the light of work recently conducted by myself in the island, that petroleum prospecting has reached a stage in New Guinea, and particularly in the Mandated Territory, where the following points await decision: (*a*) Whether the lower and pre-Miocene beds contain oil in commercial quantities; (*b*) whether there may not be areas occupied by Neogene beds which have hitherto been overlooked; (*c*) whether there may not be commercial oil accumulations on the flanks of those plutonic masses which are older than the sediments.

[16] Personal communications mainly.

Prospecting Operations.—Surface indications of the occurrence of oil are common in many parts of New Guinea, and small quantities of oil have been recovered by boring at Upoia (Vailala River) in Papua and at Matapau in the Mandated Territory.

In point of time, prospecting operations for petroleum in New Guinea fall into four divisions which overlap each other to some extent:

1. By Commonwealth Government prior to the transfer of control to the Anglo-Persian Oil Co. Ltd., 1912–1920. Expenditure:—£131,035.
2. By Anglo-Persian Oil Co. Ltd. as agents for Commonwealth Government, 1920–June 1925. Expenditure:—£227,256.
3. By private companies from July 1923 onwards. Amount expended unknown, but very great.
4. Second expedition as under (2), 1927–1929.

Private companies are still engaged in geological and prospecting work.

(*To be concluded in next number*)

MINERALIZATION IN NORTHERN RHODESIA.[1]

G. VIBERT DOUGLAS.

FROM the spirit of inquiry and the love for gain, springs forth the desire to explore. From the knowledge acquired by exploration, facts and principles are established, and it is on these facts and principles that industries are founded which secure for us our present civilization. The geographical explorations of Dr. David Livingstone during the middle of the 19th century were the first to penetrate the African Continent in those parts now known as the Rhodesias and portions of the Haut Katanga. This scientific and missionary work of over half a century ago opened the portals for subsequent explorations, which are now bearing fruit in the Congo and Southern Rhodesia and will shortly ripen into the great copper-producing zone of Northern Rhodesia.

There is a growing literature concerning the ore deposits of Northern Rhodesia. The present paper aims to consider some of the general conditions of mineralization.

In this part of Africa various types of mineralization have been distinguished:

1. *Copper and Cobalt Ore Bodies of the Katanga Type.*—These deposits are predominantly concentrations of oxide copper and cobalt ores in dolomitic rocks. They represent the concentration of carbonates and oxides by supergene waters. The following experiment was carried out for me by Mr. Simon, of N'Changa. It shows the general manner in which the concentrations are believed to have taken place.

About two grammes of pure malachite were dissolved in very dilute hydrochloric acid. The vessel which held this solution was fitted with a tap at the bottom. The solution was allowed to drop through a glass tube fitted into a large burette. The burette was filled with powdered dolomite (minus 10 plus 20 mesh). After

[1] Read before Section C., Geology, British Association for Advancement of Science. Centenary Meeting, September, 1931.

slowly percolating through the burette, the solution was caught in a flask at the lower end. It was returned to the original container morning and evening, and this process was carried on for about ten days. At the end of that time the liquor was absolutely clear and the dolomite was stained green. The grains of dolomite, when examined under the microscope, showed replacement of the carbonates of the rock by malachite.

In Nature the cycle is thought to be as follows:

(*a*) Introduction of sulphides into the rocks as hypogene solutions.

(*b*) Oxidation of the sulphides and the formation of oxide minerals of the metals by the action of the atmosphere and oxygenated waters above the water table of the country.

(*c*) Following a change in level of the water table and erosion, these oxide minerals were concentrated by the process of solution and reprecipitation as carbonates, etc., in the manner indicated by the N'Changa experiment. This general cycle as just described was repeated until the resultant concentration gave the enormous bodies of rich oxides of copper as seen in the famous opencast mines of the Congo. This concentrating action can be appreciated from the fact that ore bodies with a tenor of up to 40 per cent. copper have been produced from rocks carrying about 1 per cent. copper as sulphides.

2. *Copper (and Cobalt) Ore Bodies of the Roan Antelope and N'Kana Type.*—These deposits have been the subject of a number of papers. (See bibliography at end.) The copper minerals are in certain beds in a folded series of sediments which vary from feldspathic quartzites, shales and sandstones to massive dolomites. The values occur chiefly as sulphides, and these can be looked upon as the equivalent of the primary epigenetic sulphides, such as have been mentioned in the Congo mines, only of higher tenor.

The broad geological features of these deposits may be mentioned, as they form a most important diagnostic generalization. If the geological maps of the Roan Antelope, N'Kana, Mufulira and N'Changa be examined, it will be seen that there is a definite

geological pattern. Where the copper-bearing series (known variously as the Roan or Bwana M'Kubwa series) is in fairly close proximity to the intrusive granite, or is caught between two boss-like bodies, there the conditions are most favorable for finding ore. The beds very close to an intrusion may have been so intensely silicified as to prevent the ore-bearing solutions from entering. This silicification is associated with the magmatic stage, or, in Niggli's terminology, the ortho-magmatic stage. Niggli's second and third stages can be recognized in these Rhodesian mines, and in fact account for many field phenomena on a physical-chemical basis; for example, the pegmatites which can be seen at the Roan and N'Changa intruding the beds cannot have been responsible for all the mineralization, because they are in themselves only poorly mineralized and do not penetrate the full width of the ore-bearing beds. The last or hydrothermal stage brought the ore solutions into the beds and, depending on the structure of the permeable layers, mineralized either very intensely in a limited zone or less intensely in a greater zone. The mineralization in the Congo and at Bwana M'Kubwa represents the effects of these solutions far from their source and with no pegmatitic phase in evidence. In other words, Niggli's three stages of solidification of a magma give rise to effects on the surrounding rocks which are to be found in three concentric spheres of influence, with the hydrothermal sphere furthest out.

3. *The Zinc-lead Ore Bodies such as the Rhodesian Broken Hill and the Star Zinc near Lusaka.*—The Broken Hill ore bodies are pipe-like masses in dolomite. Their strike, dip and plunge have been controlled by fissuring and, to a lesser extent, folding. The ores were deposited as sulphides of zinc, lead, and a certain amount of copper. Oxidation by supergene waters has developed shells of oxidized ore.

4. *Quartz-Pyrite Veins.*—Sometimes carrying gold, bismuth, copper, sulphides and tourmaline. As examples of this type the Dunrobin and Matala mines in the Luiri area may be cited.

5. *Iron Manganese Deposits.*—These deposits are widely scattered over Northern Rhodesia and commonly form kopjes or hills. In a number of cases which were examined it was found

that the source of the original minerals was to be found in a shale which had been intruded by a granite. The hypogene mineralization was low. Subsequent erosion and supergene agencies have brought about concentrations of massive oxides of both iron and manganese. These deposits are akin to bog iron and manganese beds.

These five types of mineralization may not be the only types, but they represent the more important mineral occurrences. Of the five types the first two are by far the most important as representing the great copper deposits.

In Northern Rhodesia, as in other mining districts (e.g. Huelva, Spain), the mineralization of the country represents an enormous amount of energy which was expended by Nature in introducing millions of tons of compounds into the Earth's upper crust. Some of this energy went to produce the great concentrations which are of sufficient tenor to be mined. A lot of the energy was expended over a wide tract of country and resulted in no deposit of economic importance, judged by our standards of prices.

In such a country as Northern Rhodesia, where the outcrops of the really great mines are so comparatively small and are in many cases smaller than the outcrops of little or no importance, the problem arises to distinguish the great from the small. If the outcrops of the great and the small are studied, are there any diagnostic phenomena which point to any particular set of outcrops being good and another set being poor? The answer to this question is both yes and no. The study of residual limonite has thrown a certain amount of light on the subject. To me, however, there are broader criteria which illuminate this problem. These criteria shall be dealt with now and very briefly discussed:

A. Proximity to the Source of the Mineralizing Solutions.—This factor can be determined by surface mapping. If a geological map shows occurrences of an intrusive rock (e.g., a granite) in close proximity to sedimentary rocks, the area is a likely one for ore deposits.

B. The Character of the Roof Rocks.—By the "character" is

meant the structure, the permeability and the chemical composition of the rocks. All these factors can be determined by a field and laboratory study. As an example of the structural control of an ore body, the reader is referred to a paper [2] on the structural relationships and genesis of the pyritic ore bodies of Huelva.

A notable example of structural control in the Congo is the famous Kipushi Mine.

Permeability has been dealt with by many writers, as a perusal of recent numbers of ECONOMIC GEOLOGY shows. The really important fact to ascertain is whether the permeability is too widespread or whether the solutions were restricted within limits which will make the combination of rock, plus useful minerals, an economic mining proposition.

The chemistry of the host rock is of less importance than the foregoing, as the field facts show. The ores occur in sandy, argillaceous and dolomitic rocks alike.

C. The Amount of Sulphide Differentiate in the Original Source Magma.—This statement really refers to the amount of sulphide, great or small, which is released after the intrusion of the magma. To quote from Niggli,[3] "Ore deposition is a part problem of magmatic differentiation in its widest sense." This factor cannot be determined accurately, but the examination of the contacts of the intrusive rock and the intruded sediments will give a rough quantitative estimate of the sulphide released. This is a subject that requires a great deal more study and is one to which I am giving much thought. For the present the terms rich, fairly rich, and poor, are all that can be used to express the amount of sulphide differentiate released from a magma.

D. Supergene Enrichment.—This subject embraces both secondary sulphide enrichment and the enrichment and concentration of the oxide copper minerals as described in this paper.

Summary.—We shall now apply these four factors to some of the Northern Rhodesian mines and see the result of the tabulation shown in Fig. 1, especially with a view to evaluation from field evidence.

[2] Douglas, G. V.: Geol. Mag., Vol. LXVI, pp. 302–316, July, 1929.

[3] Ore Deposits of Magmatic Origin, by Paul Niggli (Boydell's translation), p. 2. Murby & Co., London, 1929.

The first six mines shown in the table are all well-known deposits. The last two are prospects in what was known as the Rhodesian Congo Border Concession. They are of no economic value at the present time.

This short account of some of the surface conditions in North-

MINE	(A) PROXIMITY TO SOURCE	(B) CHARACTER OF ROOF ROCKS	(C) AMOUNT OF SULPHIDE DIFFERENTIATE	(D_1) SUPERGENE ENRICHMENT OF CARBONATES	(D_2) SUPERGENE ENRICHMENT OF SULPHIDES	ECONOMIC OR NON-ECONOMIC
ROAN ANTELOPE	VERY CLOSE	CHANNELS CONSTRICTED	FAIRLY GREAT	NOT EXTENSIVE	CONSIDERABLE	ECONOMIC
N'KANA	VERY CLOSE	CHANNELS CONSTRICTED	FAIRLY GREAT	NOT EXTENSIVE	CONSIDERABLE	ECONOMIC
MUFULIRA	VERY CLOSE	CHANNELS CONSTRICTED	FAIRLY GREAT	NOT EXTENSIVE	CONSIDERABLE	ECONOMIC
N'CHANGA	VERY CLOSE	CHANNELS CONSTRICTED	FAIRLY GREAT	CONSIDERABLE	CONSIDERABLE	ECONOMIC
RUASHI (BELGIAN CONGO)	NOT CLOSE	CHANNELS FAIRLY WIDE	NOT GREAT	VERY EXTENSIVE	NOT EXTENSIVE	ECONOMIC
KAMBOVE (BELGIAN CONGO)	NOT CLOSE	CHANNELS FAIRLY WIDE	NOT GREAT	VERY EXTENSIVE	NOT EXTENSIVE	ECONOMIC
CHIFUMPA	NOT CLOSE	CHANNELS FAIRLY CONSTRICTED	POOR	SOME BUT NOT EXTENSIVE	NOT EXTENSIVE	NON ECONOMIC
LUAMATA	FAIRLY CLOSE	WIDE	POOR	SLIGHT	VERY LITTLE	NON ECONOMIC

FIG. 1.

ern Rhodesia should not be interpreted as obviating the use of the diamond drill. The diamond drill is the best friend of the geologist, but it is an expensive friend.

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A MAGNETITE VEIN OF ABNORMAL TYPE.

E. S. MOORE.

INTRODUCTION.

A SMALL magnetite deposit in Mongowin township, Sudbury district, Ontario is, so far as the writer can learn, unique in some respects. It is in the form of a vein about 2 to 4 inches wide composed of pure magnetite. The mineral is peculiar in that it is in botryoidal and mammillary form and the masses consist of radiating columns that at some places extend across the vein but

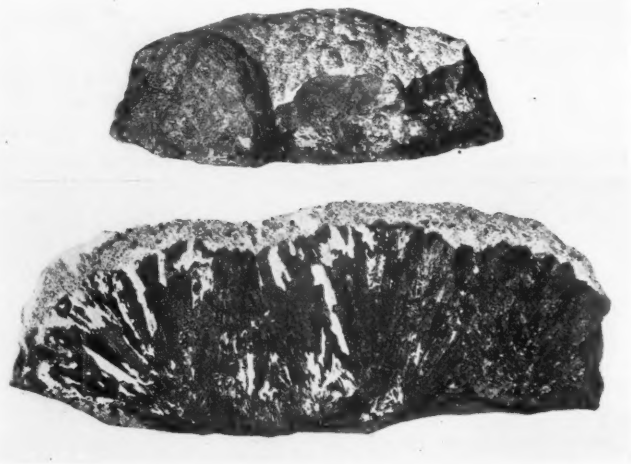

FIG. 1. Samples of radiating magnetite. The white material is dense, porcelaneous serpentine.

at others branch into radiating groups of columns (Fig. 1). Some of the columns exhibit feather-like structure. It has a glistening, highly metallic luster and bluish color on the freshly

broken surface, at places becoming iridescent on exposure. It is so unlike ordinary magnetite that it was regarded as a furnace product until actually seen in place in the field.

A brief description[1] of this deposit has been published by the writer but further tests have been made on the magnetite and associated minerals since that report appeared and the results of these are presented in this paper.

GEOLOGICAL RELATIONSHIPS

The rocks in the vicinity of the vein are of pre-Cambrian age. A boss of peridotite about 1,000 feet in diameter and probably of Keweenawan age intrudes the Gowganda formation of the Cobalt series. The peridotite consists of about 60 per cent. olivine, and 40 per cent pyroxene. The olivine is mostly altered to a mesh of fibrous serpentine. This rock is intruded by a mass of granite and along the contact a hybrid rock has resulted from contact action.

The magnetite vein lies in the peridotite about 400 feet from the granite-peridotite contact and is associated with veinlets of calcite and serpentine. The serpentine varies from a somewhat fibrous green mineral to a white and cream-colored dense type. Some of the latter is porcelaneous in appearance and resembles massive magnesite. A chemical analysis of this light-colored variety (No. 1), made by Mr. G. S. MacKenzie, gives the following figures which are compared with those of an analysis of serpentine from California.

	I.	II.*
SiO_2	41.90 per cent.	41.86 per cent.
Al_2O_3	.32	.09
Fe_2O_3	1.48	
FeO	3.34	4.15
MgO	39.44	38.63
CaO	.33	
H_2O	13.55	14.16
Cr_2O_3		.24
MnO		.20
	100.36	100.33

* Serpentine from Sulphur Bank, California. Analyst, W. H. Melville. Quoted from Data of Geochemistry, by F. W. Clarke, U. S. Geol. Survey Bull. 616.

[1] Moore, E. S.: Ore Deposits near the North Shore of Lake Huron. Ont. Dept. of Mines, 38th Ann. Rept., Part VII., p. 46, 1929.

It is evident that this mineral is similar in composition to other serpentines in which some of the magnesia is replaced by iron oxide.

The calcite in the veinlets is of two types—the ordinary variety frequently found in veins, and clear Iceland spar which is in small proportions and usually in small lenses or short veinlets in the serpentine. The calcite mostly occurs where the magnetite vein narrows and dies out in the peridotite. In some places the serpentine and calcite are mixed together. The cream-colored serpentine forms stringers or lenses in the green variety of this mineral and a thin layer of it is usually found along one side (the convex side) of the botryoidal masses of the magnetite vein.

The radiating magnetite exhibits polarity to the extent that it attracts and repels opposite ends of a compass needle but otherwise does not exhibit the ordinary properties of lodestone.[2] The slight excess of the sesquioxide, as shown in the analysis given below, over that given for pure magnetite might explain the weak lodestone effects exhibited by the mineral.

ORIGIN OF THE MAGNETITE

The ore is unusually pure magnetite. Two analyses of the mineral have been made. One, by the Provincial Assayer of Ontario gave 69.9 per cent. iron and a small residue of silicate. The other, by G. S. MacKenzie from the purest ore, showed 72.49 per cent. iron divided as follows: FeO 30.74 per cent. and Fe_2O_3 69.48 per cent. This indicates that the mineral is practically theoretically pure magnetite. Reports have been circulated that other metals have been detected in the vein, so tests were made for chromium, nickel, titanium, manganese, tungsten and tantalum, but no trace of these metals was found.

The vein when seen by the writer was exposed in a pit about 4 feet deep and had the appearance of a short, shallow vein. Further work has since been done on the deposit and, according to reports, traces of the vein have been found to a depth of 15

[2] Newhouse, W. H.: The Identity and Genesis of Lodestone Magnetite, ECON. GEOL., vol. 24, p. 62, 1929.

or 20 feet. It does not maintain a uniform width with depth but tends to finger out into stringers in the serpentine.

The peculiar crystal form of the mineral raises the question of genesis. The radiating and botryoidal structures are so characteristic of the hydrous oxides of iron that one wonders whether the vein may have originally been goethite that became metamorphosed to magnetite at the time the granite was injected. This is the only explanation that the writer can suggest to account for the unusual crystal form of the magnetite. To determine whether there might be any trace of previously existing molecular structure in the mineral, an X-ray photograph was made. The radiating magnetite was photographed in conjunction with normal isometric magnetite from Mineville, New York. The minerals were finely powdered and the X-ray picture shows quite clearly that the lines obtained for the two minerals are practically identical. There is no evidence of pseudomorphism after a hydrous oxide in so far as any internal molecular structure is concerned, nor is there any definite evidence of such replacement in the external crystal form.

ACKNOWLEDGMENTS.

The writer wishes to express his sincere thanks to Mr. G. S. MacKenzie, Research Assistant in Geology, University of Toronto, for making the analyses included in this paper, and to Mr. H. J. C. Ireton, of the Department of Physics, for taking the X-ray photograph of the magnetite.

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DISCUSSION AND COMMUNICATIONS

THE RESEARCH PROGRAM OF THE ILLINOIS GEOLOGICAL SURVEY.

THE new mineral research program which has just been inaugurated by the Illinois State Geological Survey will undoubtedly prove to be just what the mineral industries of the State have been needing, in order that they may recover ground which they have been steadily losing in recent years.

The research program provides for a complete scientific investigation into the composition and potential economic possibilities of all mineral and rock substances occurring in Illinois, and also provides for the study of production and movements of mineral materials both into and out of the state, and of all possible marketing opportunities.

The Geological Survey's staff has been recently enlarged in order to carry out these researches, a trained corps of chemists and physicists having been appointed to participate with the regular geologic staff in this respect.

Their investigations will be carried on in the new Mineral Research Laboratories, which were recently dedicated, and which have been provided by the University of Illinois adjacent to the Geological Survey offices in Urbana.

The investigators have various types of up-to-date laboratory equipment at their disposal in the new quarters, and they are already actively engaged with a number of projects that promise to benefit several mineral industries. All findings will be revealed for the benefit of the mineral industries when their soundness is established, in each case.

The leading natural products that will be subjected to scientific investigation are: coal, oil and gas, clay, shale, limestone,

sandstone, sand and gravel, molding sand, fullers' earth, fluorspar, silica sand, tripoli, and ochre.

During its 26 years of geologic field investigations the Geological Survey has outlined tremendous reserves of these natural earth substances, which need the proposed research to reveal their true nature and value for many uses in the chemical, metallurgical, structural, power and agricultural industries.

The research program, as outlined above, had its origin in organized activity on the part of the Illinois Mineral Industries Committee, which was formed in 1930 for the purpose of putting the plan into effect by securing favorable legislation and adequate appropriations, after the proposal was approved by the State Board of Natural Resources and Conservation. Practically every mineral industry in the State was represented on this committee.

Besides detailed studies of individual mineral substances, attention will also be given to the possibility of blending different mineral and rock substances for the manufacture of commercial products not now being produced by the industries.

Additional research will be directed towards the location and utilization of materials that have not found their way into industry to date.

FIELD AND LABORATORY FACILITIES.

To attain these and other objects within the scope of the Geological Survey, the Survey is adopting the most modern devices for field investigations and is providing laboratory facilities for fundamental physical and chemical studies of the earth's materials and of problems of their utilization, using whenever available special equipment in the laboratories of the University.

Geochemical Laboratories.—The geochemical laboratories of the Survey include an analytical laboratory, a special fuels laboratory, a special non-fuels laboratory, a high temperature laboratory, and an industrial research laboratory.

The analytical laboratory is equipped for proximate and ultimate analysis of coal, analysis of rocks, clays, silica sands, coal

ash, brines, etc., extraction and analysis of oils, analysis of gases by the Shepherd modification of the Orsat equipment, and also analysis of gases, particularly natural gas, by low temperature fractionation with the Podbielniak equipment.

The fuels laboratory is furnished with suitable equipment for fundamental chemical studies in regard to the composition and constitution of coal, oil and gas.

The non-fuels laboratory has equipment suitable for physico-chemical studies on the non-fuel minerals.

The high-temperature laboratory contains gas and electric furnaces for the use of the analytical and research laboratories and an electric pyrometer which is connected through a multiple point switch to thermocouples from each furnace where temperature control is desired.

Provision is made for equipment for fundamental studies on problems of industrial application of research results, in the industrial research laboratory.

The University of Illinois, in its Department of Chemistry, will coöperate in the use of its X-ray equipment on problems requiring X-ray photographs.

Laboratory of Coal Microscopy.—This laboratory of the Coal Division is equipped to obtain complete columnar samples of the coal beds, to prepare polished sections and thin sections, to examine these under high-power microscopes, and to photograph thin sections on a magnification as high as approximately 1000 diameters. In this laboratory the maceration products of coal are also studied as a part of the study of the constitution of coal.

Non-Fuels Laboratories.—The non-fuels laboratories are equipped in themselves, or with the coöperation of the State Highway Division and the Department of Ceramic Engineering of the University of Illinois, to undertake the wide variety of physical tests and studies necessary to determine accurately the physical composition and properties of the state's non-fuel minerals. Modern laboratory crushing and drying machinery for preparing earth materials for study is provided, as well as microscopes for the examination of these materials and their commercial products.

Laboratory of Sedimentary Petrography.—This laboratory is equipped for the making of thin sections of unconsolidated materials, as well as consolidated, for the separation of heavy minerals, and for the microscopic determination of mineral and rock constituents.

Laboratory of Geophysics.—This laboratory is equipped for the study of such features of oil sand cores as porosity, texture, saturation with oil, etc., and for the determination of oil reserves in the various oil-sand horizons of the State's oil fields.

Equipment for field geophysical studies includes an Askania magnetometer and a Megger apparatus for determining electrical resistivity of earth materials.

M. M. LEIGHTON.

ILLINOIS STATE GEOL. SURVEY,
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REVIEWS

Congrès International des Mines, de la Métallurgie et de la Géologie Appliquée, VI^me^ Session, Liége, 1930. 4^to^, 1931.

Vol. I., Section des Mines. Pp. 484, figs. Price, $5.00.

Vol. II, Section de Métallurgie. Pp. 952, figs. and 20 plates. Price, $7.75.

Vol. III, Section de Géologie Appliquée. Pp. 434, pls. 22. Price, $6.00.

This collection of papers read at the Liége session of the International Congress in June, 1930, covers a wide variety of subjects in the fields indicated in the titles. The volume on mines contains 54 articles divided into 7 groups, as follows: freezing preparatory to sinking pits; extraction of ore; production and utilization of energy; modern methods of exploitation of oil, coal, metalliferous deposits and quarry products; ventilation; mechanical preparation, and miscellaneous. The section on metallurgy comprises 96 articles, on blast furnaces; steel and ferrous alloys; metals other than iron; non-ferrous alloys; combustibles; foundries; high resistant iron and wrought (malleable) iron. In the section on applied geology are 59 articles, including 17 on metallogenesis, 11 on combustibles, 5 on hydrology, 12 on geophysical prospecting, and 14 on miscellaneous topics. The greater number of the articles are in French, but a few are in Italian, English, or German. Most are well illustrated with text figures and reproductions of photographs.

Among the noteworthy articles on geology are the 6 on diamonds, mainly in Angola and the Belgian Congo. The article by W. Beetz, on diamond concentration in alluvial placers, is particularly interesting in that it analyzes the differences in the depositional processes of "dry rivers" and of those in humid regions, and describes the enrichment of sands by wind action.

An article by J. D. H. Donnay is worthy of mention since it calls attention again to the copper deposits of the Engels mine in California, and argues in favor of their "late magmatic origin" rather than the hydrothermal origin assigned to them by Graton and McLaughlin.[1]

[1] See also article by A. Knopf and C. A. Anderson in ECONOMIC GEOLOGY, Vol. XXV (1930), pp. 14–35, in which the conclusion is reached that the ore was deposited by gaseous solutions under conditions analogous to those attending the deposition of contact-metamorphic copper ores.

The summaries of the composition and method of origin of the bauxites of France, by De Lapparent, and of those near Mostar in Herzogovina, by Yakchitch, are also interesting, the latter partly because of the possible commercial importance of the deposits.

In the group of papers on the combustibles, that on the algal coals by Paul Bertrand will perhaps attract most attention, partly because of the excellent reproductions of photographs with which it is illustrated. They furnish corroborative visible evidence of the presence of abundant algae in the deposits from which boghead coals were made. But the paper by A. Duparque on the correspondence between the industrial properties of coals and the chemical composition of the vegetal substances from which they were derived is equally interesting. It deals largely with classifications of coals based on chemical properties and on the causes of their differences. These causes he discusses under two heads: (1) The rôle played by the nature of the original deposit, and (2) the rôle played by secondary processes. The first he regards as the more important, and he appears to consider the character of anthracite as being due largely to the absence of cuticles and spores from its ancestral deposit. This paper is also richly illustrated.

Of the 7 articles on petroleum, perhaps the one most conducive to thought is that by E. Kraus on the general thesis that all beds in which petroleum and coal originated were deposited at depth, and that paleogeographic, orogenic, and tectonic conditions determine the character and the position of coal and oil deposits.

In the group of papers on geophysical prospecting, that by Sundberg and Nordstrom on the results of electrical prospecting is interesting because of its simple statement of the theory of the method and the detailed description of its application to the discovery of ore deposits in Sweden, the East Indies, and elsewhere, and of its success in detecting buried structures, mainly in oil fields. H. Neville contributes an acount of the working out of the structure of a coal bed in Holland, and of irregular deposits of hematite on the top of an irregularly eroded limestone, by seismographic methods. E. Roux follows with an account of the history of the development of instruments used in seismographic investigations, and C. M. Schlumberger with illustrations of the use of the electrical resistance method of prospecting.

In the miscellaneous group of papers should be mentioned Joleaud's article on potash deposits in South Tunisia; Dalloni's article on the potash deposits in the Landes region, France; and A. Kumm's description of his investigations on the reasons for landslides in shale talus [Boschungsrutschungen in Tone].

Many other articles of nearly equal importance to those cited appear in the volume, but they cannot be referred to individually in this place,

because of lack of space. Those mentioned may have a little stronger personal appeal than those which have not been referred to specifically.

W. S. BAYLEY.

The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals. By A. N. WINCHELL (with chapter on universal stage, by R. C. EMMONS). 2d ed. Pp. 402, figs. 311, pls. 5. John Wiley & Sons, New York. Price, $5.00.

The book is divided into three parts: I, Principles and Methods; II, Descriptions of artificial inorganic solids or artificial minerals; III, Determinative Tables.

In this revised edition, Part I is entirely added, being taken, according to the author's prefatory statement, from his Elements of Optical Mineralogy, Part I. Part II has been thoroughly revised, and Part III has been entirely rewritten. The addition of Part I is particularly valuable, since it forms a 150-page text on the principles of optical mineralogy. The value of Parts II and III is too well known to need comment. The book represents an enormous amount of work and constitutes an extremely valuable compendium of the microscopic characters of these little known substances.

Petroleum in the United States and Possessions. By RALPH ARNOLD AND WILLIAM J. KEMNITZER. Pp. xxi + 1052, maps 2, figures 37, tables 91. Harper and Brothers, New York and London, 1931. Price, $16.00.

This book is the first of four volumes which will cover the petroleum industry in all its phases. It is an excellent and very complete reference work.

Following a short preface and introduction, the text is divided into two parts. Part I. (855 pages) relates to the history, geology, technology and future possibilities of producing areas, first in the United States as a whole and then by major fields and districts. Petroleum in each state or major area is taken up under the following headings: (1) Historical Review, with a chronological outline of development; (2) Geological Review, listing alphabetically the producing gas and oil fields with the character of their products, the stratigraphy (generalized sections, source, reservoir and cap rocks), structure, physiography and geography, classification of land for oil and gas; (3) Technological and Statistical Review, with a description of exploration, drilling methods, development and production; (4) Review of Economics, discussing prices, investments and returns; (5) Future Possibilities; and (6) Acknowledgments, sources of information and bibliography.

Part II. (137 pages) gives in briefer form the same subjects in non-productive areas.

Two colored maps of the United States 7½ × 10 inches) are provided: a geological map in 18 colors and an outline map in four colors, the latter showing the present proven oil and gas fields together with a classification of lands for petroleum (impossible, unfavorable, prospective, proven). Three indices conclude the book: of authors in bibliographies (9 pages), of subjects in bibliographies (24 pages), and an index to the text (20 pages). Exhaustive bibliographies are given on all areas.

This book is a most conscientious piece of work. The fundamentals and essentials of the petroleum industry have been treated as completely as space would permit. The bibliographies are invaluable. Undoubtedly the volume will be an indispensable addition to the library of any person interested in the oil industry.

The principal criticism that can be directed toward the book is caused by the absence of reference maps of the different producing areas. It is difficult to follow the text without adequate maps.

The desire to be concise has possibly resulted in certain incorrect generalizations, especially when dealing with the stratigraphy of reservoirs and source rocks (p. 16). The terms Carboniferous and Permian are used in a confusing way (p. 13). The term Juratrias is an ambiguous one, especially in oil geology, and should be avoided (p. 13). Tertiary and Quaternary sediments on the Gulf Coast of Texas are underlain by Mesozoic and not Paleozoic formations (p. 12). Deep-seated Gulf Coast production, if any, will probably come from Jurassic or Cretaceous sources rather than from Paleozoic shales (p. 15–16). The authors appear to underestimate the possibilities of Mesozoic production; no mention is made of quite probable Middle Jurassic and Cretaceous source rocks in Southwest Texas (p. 421) and the Gulf Coast; also the bulk of the Rocky Mountains production comes not from Paleozoic but from Upper Cretaceous sources (p. 613).

The correlation of the Ordovician of New York State (p. 120) does not correspond to modern ideas and accepted usage. The inclusion of the Medina in the Ordovician and of the Chazyan in the Canadian is not to be commended. The Wilcox sand of Oklahoma is of Lower Middle Ordovician (Black River) and not of Devono-Silurian age (p. 393).

The term MID CONTINENT has been extended to include an enormous amount of territory, which results in misleading generalizations and difficulties in following the description of this area.

In the table on page 49, the return on investment per well drilled in Michigan should show a loss instead of a profit if the rest of the table is correct.

There are a few errors in spelling, mostly of place and formation names (Hwionian for Huronian on p. 900, etc.).

The authors take a definite stand in the question of overproduction and low prices on oil. They ascribe this situation to the imports of cheap foreign oil rather than to the unorganized activities of independent operators.

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Handbook of Chemical Microscopy. By E. M. CHAMOT and C. W. MASON. Vol. II. Pp. 411, figs. 179. Wiley & Sons, New York. Price, $4.50.

Microchemistry has long been utilized by chemists, but only recently has it been widely adopted by geologists and mineralogists for the determination of small particles of minerals and rocks. Within a year, two books have appeared for the use of economic geologists and mineralogists in the microscopic determination of opaque minerals, both of which utilize microchemical methods as important tests. All geologists who study opaque ores by reflected light have often been baffled in the identification of minute particles. The answer is the use of microchemical methods. Short, in his recent book,[1] gives methods by which the needed material may be obtained from the polished surface, and summarizes the common tests.

This book, however, although written for the chemist, is invaluable to the geologist, for it is the most complete work in English on the subject, and it should be used by every geologist who studies polished surfaces of ores. Volume II deals with the manipulative methods for small quantities and gives the procedures for detection of the elements. Later chapters deal with the detection of anions, special reagents, and qualitative analysis of unknowns. Numerous plates picture the characteristic crystals that are formed and render comparison easy.

Volume II is complete for the chemist and contains more tests than the geologist would ordinarily use, but those that he needs are given in great detail. The volume is characteristic of Wiley's good bookmaking, and I heartily recommend its use by all geologists who study ores under the microscope.

Volume I (1931; pp. 474, figs. 149. Price, $4.50) deals with the principles and uses of the microscope and accessories, and the physical methods for the study of microchemical problems. It is chiefly to acquaint the chemist with the geologist's tools and microscopic procedure, and is therefore not so valuable to the geologist. However, for those who desire technique in microscopic methods Volume I is a handy companion for Volume II.

ALAN BATEMAN.

[1] Short, M. N.: Microscopic Determination of the Ore Minerals. U. S. Geol. Surv. Bull. 825, 1931.

Science and First Principles. By F. S. C. NORTHROP. Pp. 299. Macmillan Company, New York, 1931. Price, $3.00.

This able young philosopher of Yale University, equipped with a scientific background, has set forth in the language of the layman what science is doing, what it means, what contemporary discoveries in one branch mean with respect to another, and what all this means for philosophy.

He discusses the trend of science from the time of the Greeks to the present, to determine what concepts and principles are fundamental. The reader is enlightened regarding relativity, quantum and wave mechanics, thermodynamics, life, man and his physiological nature, heredity and logical character. The findings of one science illuminate those of another and a new scientific philosophy is presented.

Although difficult reading in places, it is interesting and new thought is presented.

Prospecting for Gold. By I. L. IDRIESS. 3d Ed., enlarged. Pp. 272, illus. 20. Angus and Robertson, Ltd., Sydney, 1932. Price, 5s.

The value of this work to the prospector is indicated by the fact that it is now in its third edition. It is designed to "provide information which will be of service to the man who is setting out on his first prospecting venture as well as the more experienced prospector who is desirous of adding to the sum of his knowledge." It discusses the methods to employ in prospecting placers for gold, tin, and wolframite, and in the prospecting for gold in reefs. In addition are two chapters on the search for and the mining of opal.

The book is practical. It describes in detail the methods of approaching the problems and the tools required in the field, and outlines the means employed in overcoming difficulties encountered in the search for the valuable products. It gives clear instructions for making the larger pieces of apparatus that are frequently required in the course of the work and gives directions for securing the most trustworthy results under various conditions. There are chapters on sluicing, dam building, dry-blowing, amalgamation and many of the other processes that the prospector needs to apply if he wants to be sure that he has learned all to be known about the possibilities of the location in which he is working. There are many hints as to the most satisfactory ways of handling his "dirt" and many short-cuts suggested for reaching accurate conclusions when working on small quantities of material. The clear directions given for constructing crude but efficient apparatus for temporary use are worthy of note. These are illustrated by plans that any mechanically minded person may easily follow. It is true that the book is written for Australians, but much of the information given in it is applicable anywhere.

W. S. BAYLEY

BOOKS RECEIVED.

By

D. GALLAGHER.

Geologie der Schweiz, Geotechnische Serie, XVI. Lieferung, Heft 2. Pp. 103, figs. 28, pls. 11. Berne, 1931. Contains: Die Blei-Zinklagerstätten von Goppenstein, by H. F. HUTTENLOCHER; Die Erzlagerstätten am Parpaner Rothorn, by F. DE QUERVAIN; Les gisements de mispickel aurifères d'Astano, by J. DUBOIS.

Gebirge am Mittelmeer. By W. VON SEIDLITZ. Pp. 651, pls. 14, figs. 140. Gebrüder Borntraeger, Berlin, 1931. Description, analysis, and synthesis of mountain structure in the lands bordering the Mediterranean Sea.

Geologia del Perú, etc. By G. STEINMAN. Pp. 448, pls. 6, figs. 271. Carl Winters, Universitatsbuchhandlung, Heidelberg, 1930. Price, $6.00. A translation into Spanish of Steinmann's "Geologie von Peru," which appeared in a German edition about two years ago. The translation is under the direction of Dr. J. A. Broggi, Secretary of the Geological Society of Peru.

The Crystal Cavities of the New Jersey Zeolite Region. By W. T. SCHALLER. Pp. 90, pls. 32, figs. 33. U. S. Geol. Surv. Bull. 832. Washington, 1932. Price, 45 cts. Origin, mineralogy, pseudomorphism; extremely interesting.

Geology and Ore Deposits of the Bonanza Mining District, Colorado. By W. S. BURBANK. Pp. 166, pls. 35, figs. 47, maps in color. U. S. Geol. Surv. Prof. Paper 169. Washington, 1932. Price, $2.00. General geology and structure of the region, economic geology of the ore deposits, and descriptions of the mines and prospects.

Thirty-third Annual Report of the Mining Industry of Idaho, 1931. By S. CAMPBELL, Inspector of Mines. Pp. 298, figs. 46. Boise, Idaho. Present status of mines and mining by counties.

The Lawrence Clay of Lawrence County. By W. STOUT, M. C. SHAW, G. A. BOLE, AND D. SCHAAF. Pp. 134, pls. 4, figs. 22. Geol. Surv. of Ohio, 4th Ser. Bull. 36. Columbus, 1931. Many detailed sections and analyses, utilization possibilities, testing methods.

Investigations in Ore Dressing and Metallurgy, 1930. Pp. 215. Canadian Dept. of Mines, Mines Branch, No. 724. Ottawa, 1932. Contains 43 reports on a wide variety of investigations by many authors.

The Geology of the Country South of Piet Retief. By W. A. HUMPHREY AND L. J. KRIGE. Pp. 67. Union of South Africa Geol. Surv. An explanation of Sheet No. 68 (Piet Retief). Price 5/ including map. Pretoria, 1931.

Ochers and Mineral Pigments of the Pacific Northwest. By H. WILSON. Pp. 74, figs. 18. U. S. Bur. of Mines, Bull. 304. Washington, 1929. Price, 15 cts.

Carbonizing Properties of Davis Bed Coal from Garrett County, Md., and of Mixtures with Pittsburgh Bed Coal. By A. C. FIELDNER, J. D. DAVIS, E. B. KESTER, W. A. SELVIG, D. A. REYNOLDS, AND F. W. JUNG. Pp. 39, figs. 33. U. S. Bur. of Mines, Tech. Paper 511. Washington, 1932. Price, 20 cts.

Le Centre Africain. By M. ROBERT. Pp. 261, figs. 10, pls. 13. M. Lamertin, Bruxelles, 1932. Treatise on the Congo mining region and the Congo Basin.

Geology of the Ruhuhu Coalfields. By G. M. STOCKLEY AND F. OATES. Pp. 62, pls. 6, maps and figs. 5. Tanganyika Geol. Surv. Bull. No. 2. Dar es Salaam, 1931. Price, 5/.

Coal in India. I. The Natural History of Indian Coal. By C. S. FOX. Pp. 308, pls. 17. Memoirs of the Geol. Surv. of India, vol. LVII. Calcutta, 1931. Price, 15/6. Occurrence, physical and chemical characters, and factors in the formation of coal.

Canada Geol. Surv., Summary Report, 1930, Part D. Pp. 143, figs. 5. Ottawa, 1931. Contains: Thetford Map-area, Quebec, by H. C. COOK; Chemical and Mineralogical Studies of Some Quebec Chromites, by E. POITEVIN; Southern Part of Opemiska Map-area, Quebec, by C. TOLMAN; Thicknesses of the Ordovician Formations in Ontario and Quebec, by D. C. MADDOX; Heavy Minerals in the Basal Ordovician Sandstones of Ontario and Quebec, by F. J. FRASER; Silica Deposits at Leitch Creek and Skye Mountain, Cape Breton, N. S., by E. A. GORANSON; Deep Borings in Ontario, Quebec, and the Maritime Provinces, by W. A. JOHNSTON.

Geological Map of India. Full color. Scale 1″ = 32 miles. Geol. Surv. of India, Calcutta, 1931. In eight sheets, each 20.3″ x 36.8″. Price, 8 sheets, 16 Rs.

Pit and Quarry Handbook.—34th Edit. Pp. 818. Complete Service Publ. Co., Chicago, 1931. Complete data pertaining to pit and quarry, non-metallics, extraction, and industry.

Investigations of Fuels and Fuel Testing, 1929. Pp. 131, illus. 16. Canada Dept. Mines, Mines Branch, No. 721. Ottawa, 1932. Contains six papers.

Annual Report of the Dept. of Mines, Canada, 1931. Pp. 61. Ottawa, 1931. Price, 25 cts.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.

SCIENTIFIC NOTES AND NEWS

O. A. L. Whitelaw, for eleven years Director of the Gold Coast Geological Survey, has resigned his position.

Arthur R. Andrew has succeeded James Park, who recently resigned, as Professor of Mining in the University of Otago, Dunedin, New Zealand. Dr. Andrew has been in charge of the Shell Royal Dutch Co. work in the United States and lately has been consulting geologist in New Zealand.

E. C. Andrews has retired from the position of Government geologist of the Department of Mines, New South Wales, to devote his time to preparation of several works for publication.

D. F. Kidd, of the Canada Geological Survey, a recent contributor to this journal, has gone to Great Bear Lake, via airplane from Waterways, Alta., to continue investigations of pitchblende and silver occurrences.

Hans Merensky has left the Transvaal on a visit to England.

E. L. DeGolyer of New York City has removed his offices to Suite 2703, 120 Broadway.

John A. Allen, Chairman of the Department of Geology, University of Alberta, has been elected President of the Canadian Mining Institute.

A. L. Hall, who recently retired from the post of assistant director of the Geological Survey, Union of South Africa, has been given the first award of the Draper medal, lately established in memory of Dr. David Draper.

L. T. Nel has been elected president of the Geological Society of South Africa.

V. Dolmage has been elected president of the British Columbia Chamber of Mines.

George Otis Smith's appointment as Chairman of the Federal Power Commission, recently referred to the U. S. Supreme Court, has been confirmed by unanimous opinion of the Court.

Roswell W. Prouty, after two years as consulting geologist for Tzvetmetzoloto (Non-ferrous Metals and Gold Trust) in the Trans-Caucasus, has returned to this country and is now at Los Angeles.

T. A. Rickard has received from the Institution of Mining and Metallurgy the Gold Medal for 1932, "in recognition of his services in the general advancement of mining engineering, with special reference to his contributions to technical and historical literature."

G. Vibert Douglas has returned to Montreal after two years spent in professional work in Northern Rhodesia.

Walter S. Larsh, of the Nevada Consolidated, has been spending some time in southern Nevada examining properties there.

Basil Prescott is at El Paso, Texas, 1113 East River Street.

Joseph Hornberger, Jr., is appointed assistant geologist of the Bureau of Economic Geology of the University of Texas at Austin.

Harold S. Wilson, lately geologist with the Nipissing Mining Company, has now opened an office as consulting geologist and mining engineer at Cobalt, Ontario.

The Kentucky Geological Survey has been temporarily discontinued and its affairs are under the supervision of the University of Kentucky at Lexington.

The Colorado School of Mines will offer a six-weeks course, beginning July 11, on the principles and practical application of geophysical methods, including field work near Golden.

The Sixth Annual Conference of the Kansas Geological Society will be held August 28 to September 3, convening at Wichita on Saturday evening, August 27, and concluding at Omaha, Nebraska, September 3. A study of Interior Permo-Pennsylvanian in Kansas, Nebraska and Missouri is planned. For particulars address Edward A. Koester, 421 Fourth National Building, Wichita, Kan.

The American Association for the Advancement of Science will hold its summer meeting at Syracuse, N. Y., June 21–24. The program of Section E, Geology and Geography, includes a symposium on physiographic and glacial problems; papers and discussions on the stratigraphy of Central New York; and several field trips.

Ontario and Quebec, through J. A. Dresser, have arranged a summer excursion, July 31 to Aug. 7, for the Society of Economic Geologists and all others interested to visit the gold camps of Kirkland Lake, Rouyn, Porcupine, and Siscoe, assembling at North Bay. Total expense from New York, about $115, or from North Bay, $65. Anyone desiring to take advantage of this unusual opportunity is asked to notify Professor Edward Sampson, Princeton University, at once.

J. H. L. Vogt, of Trondhjem, Norway, died on January 3, at the age of 73. Since 1912 he has been connected with the Institution of Technology at Trondhjem, until his resignation a few years ago. Of his important scientific writings the best known is his "Die Erz Lagerstätten," written in collaboration with Beyschlag and Krusch, which ranks as a classic in its field. In 1929 he was the recipient of the Penrose Medal from the American Society of Economic Geologists.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.